G. H. Westby

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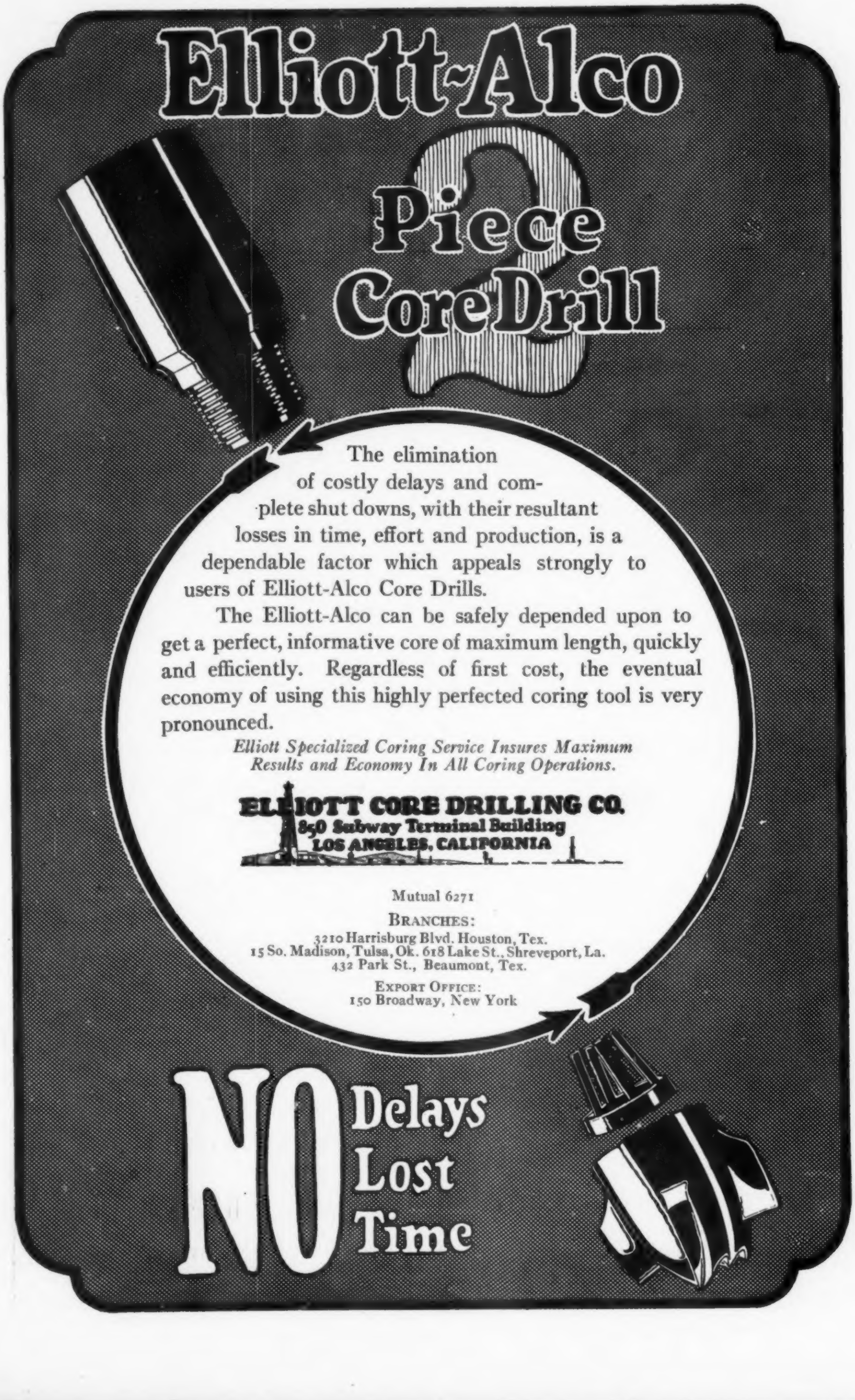
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GEOLOGY OF NORTHWEST PERU[1]

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Toronto, Canada, and Gloversville, New York

ABSTRACT

The oil fields of northwestern Peru occur in an area of much faulted Tertiary rocks, extending from the southern border of Ecuador (about 3° 30′ south latitude) south about 225 miles (to about 6° south latitude). It is the northern end of a desert belt extending along the entire Peruvian coast, but near the northern border, merging rapidly with the semi-arid and humid forest zone of southern Ecuador.

The presence of oil in this region has been known from a very early date, and in Colonial and pre-Colonial times, several of the larger oil seeps were worked for their pitch or brea. To-day there are three general districts where commercial production is obtained: the Zorritos district in the northern part, where production is derived from the lower Miocene or upper Oligocene; farther south, the Cabo Blanco-Lobitos district; and the Negritos-La Brea district. In these latter and more important fields, the oil is derived principally from Eocene sediments.

The Tertiary of this region, which at present is the source of the entire Peruvian production, has a total thickness of about 25,000 feet. This section is exceptionally complete, generally marine and fossiliferous, and on the basis of detailed stratigraphic and paleontologic studies, it has been subdivided into about 14 mappable units or formations. The beds range in age from early Eocene to Pliocene. They rest either upon an incomplete development of Cretaceous, or, more generally, on older mountain rocks such as Pennsylvanian slates. These Pennsylvanian metamorphics, closely associated with a granite intrusion, form most of the mountain region toward the east and a few other outlying areas.

The major structural features of the region are the main Andean or mountain ranges on the east, and a Pacific fault which closely follows the edge of the continental shelf on the west. In the intervening area, the Tertiary rocks have been locally folded into smaller anticlines and synclines and extensively block faulted. The rocks are everywhere much faulted, and the local structure consists principally of many small fault blocks. Most of the faults are normal.

[1]Presented before the Association at the New York meeting, November 16, 1926. Manuscript received by the editor, September 6, 1927. Published by permission of A. M. McQueen, vice-president, and O. B. Hopkins, chief geologist, of the International Petroleum Company, Ltd., Toronto, Canada.

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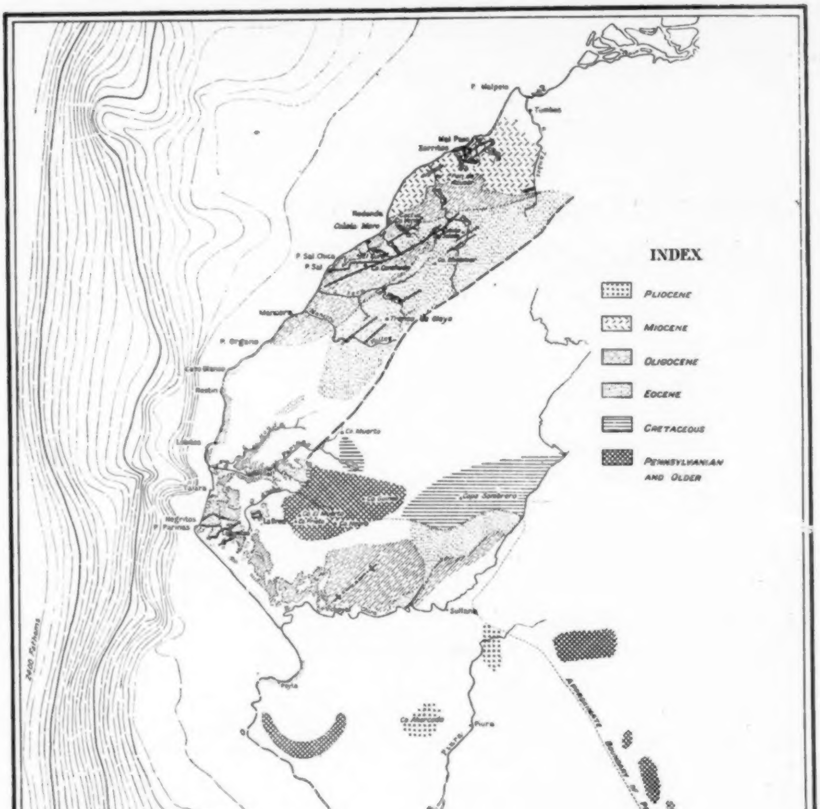


FIG. 1-A.—Geological map of Northwest Peru.

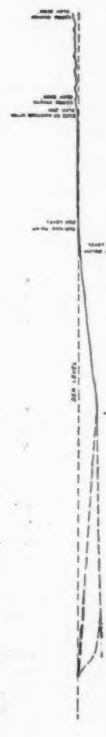


FIG. 1-B.—Profile showing continental shelf and adjoining land mass at Parinas Point.

Introduction

The authors' purpose in writing this paper is to present a brief outline of the geology of that portion of northwest Peru which extends from the coast inland to the foothills of the main Andean range. Some suggestions will be made regarding a revision of formational names used in previous reports and additional names will be introduced. Since the members of the Association are particularly interested in the petroleum deposits of the region, special attention will be given to their occurrence and development.

The area under discussion is located between latitudes 3° 30′ S. and 6°50′ S., and between longitudes 79°30′ W. and 81°20′ W. Its extent is about 225 miles north and south and its maximum inland extension is about 90 miles. Parinas Point, the most westerly point of South America, is located a little north of an east-west line drawn through the center of the area (Fig. 1).

The data presented here have been secured by the geologists of the International Petroleum Company, Ltd., working under the able direction of their chief geologist, O. B. Hopkins, and it is through their kindness that it is possible to present this paper.

Among the field geologists to whom special credit is due are O. D. Boggs, J. L. Stauft, C. W. Boughton, E. N. MacCormack, J. S. Stewart, E. Emendorfer, and J. V. Culbert.

A part of this area, notably the La Brea-Parinas Estate, which includes the greater part of the territory between Quebrada Honda on the north, the Amotape Mountains on the east, Chira River on the south, and the coast line, has been mapped in detail. The remainder of the district has been mapped in a fairly accurate reconnaissance way.

The lower part of the geological column which will be described later has been secured largely on the La Brea-Parinas Estate as a result of the detailed work in that district. The upper part of the section was secured, in part, in the Zorritos district and in part at Bayovar. The areal distribution of the separate formations is not shown on the accompanying map for two reasons: (1) because there are some problems of correlation which have not been worked out to our entire satisfaction, and (2) because more detailed work will be required in the areas where at present only reconnaissance work has been done, in order to locate accurately formation boundaries and the details of the structural features. As a result only the major divisions are shown. It is hoped that at some future time we shall be able to present a paper outlining in greater detail these different features.

The paleontology of the region will be the subject of separate papers, in which the faunal characters of the formations will be treated in detail.

The region described in this paper is the northern part of a desert belt which extends north from Chile along the entire west coast of Peru. As a rule there is but little vegetation and this is chiefly in the area north of the Mancora valley, rapidly increasing toward Tumbes. In most of this region there is practically no rainfall, except at approximately 30-year intervals. These periods of precipitation are brought about mainly through changes in the ocean currents. Although the district is but a few degrees south of the equator and rises only a few feet above sea-level, the maximum temperature is generally not greater than 95° F., and the minimum is about 60° F. This low uniform temperature is a result of the cool Humboldt Current which flows northward along the west coast. This current is also directly responsible for the arid character of the coast.

General Geology

Topography

The region may be described as a series of terraces whose combined width ranges from 16 to 90 miles. They extend north and south as a narrow band between the foothills of the Andes and the sea coast. The elevation of this narrow strip of land rises gradually from sea-level on the south to a maximum of about 1,500 feet in the north. A gentle slope also extends from the base of the mountains toward the sea where the ocean waves have cut an escarpment which rises, in places, to a height of nearly 1,000 feet.

This uplifted area is traversed by three major streams, Piura River in the south, Chira River near the central portion, and Tumbes River on the north. The source of water for these streams is in the mountains on the east. They have cut valleys varying in width from one to several miles. In places the sides of these valleys rise gently to the general level of the surrounding country, but at other places steep escarpments several hundred feet high have been formed. The water of Piura River gradually decreases in amount as it extends into the desert until it finally disappears. The other two streams are permanent throughout their entire lengths.

In addition to the major valleys just mentioned, several minor valleys extend from the sea to the foothills of the mountains. Chief among these are Parinas, Mancora, and Boca Pan. They are deep

and narrow, with steep walls throughout the greater part of their length, and have been developed by intermittent streams.

Many smaller valleys have been cut back from the sea coast and have developed a narrow band of "bad-lands" type of topography. North of the Mancora valley erosion has been greatest and the plain-like surface which is characteristic of the area on the south has been completely destroyed. The development of the topography of this area has been controlled by the difference in hardness of the different Tertiary strata and by their structural positions. As a result, strike ridges and valleys are very conspicuous features.

The most important result of this erosion, geologically, is the removal of the covering of gravel, shale, and sand, and the exposure of the Tertiary deposits. In the areas where such erosion has not taken place, the character and position of the Tertiary strata are purely conjectural.

The minimum width of the area is east of Negritos where the Amotape Mountains come to within 16 miles of the sea coast. These mountains form a small spur from the main Andean range, and extend in a direction approximately S. 50° W. Immediately south of this range the coastal belt attains its maximum width of approximately 90 miles, although on the north the maximum width is about 25 miles. East of Negritos the mountains attain an elevation of 3,500 feet and increase in height to the northeast.

A group of hills, known as the Cerros de Illescas, are found in the southern part of the area, south of Sechura Bay. They cover an area about 15 miles long by 10 miles wide and reach an altitude of about 1,200 feet. They form a prominent topographic feature as they rise sharply from the ocean on one side and the low desert plain on the other.

A somewhat similar group of hills called the Silla de Paita are found south of Paita in the south-central part of the area.

An area of low land near sea-level is found along the coast between Negritos and the Chira valley. This land is known as Salinas on account of the salt deposits found by the evaporation of incoming water. A narrow beach ridge separates this low land from the ocean.

STRATIGRAPHY

The rocks exposed in this area range in age from Paleozoic to Recent (Table I). This section, however, is far from complete and the succession and exact age of the older beds is still very imperfectly known.

TABLE I

GEOLOGICAL FORMATIONS OF NORTHWEST PERU

American Time Sub-Divisions				Formational Names adopted in this paper	Bosworth's Classification	Spieker	Grzybowski
CENOZOIC	Quaternary	Pleistocene		Lobitos Talara Mancora	Same		Paita (Pliocene acc.Grzy.)
	Tertiary	Pliocene		Sechura			
		Miocene	Upper	Tumbez			
			Middle	Cardalitos		Talara	Talara (see below)
			Lower	Zorritos		U. Zorritos Variegated L. Zorritos	Zorritos
		Oligocene	Upper	Heath	Zorritos	Heath	Heath
			Middle	Mancora (Punta Bravo grits) (Mirador congl.)			
			Lower	Chira (Bayovar) Verdun	Lobitos		
		Eocene	Upper	Saman			Talara (U. Miocene acc. Grzy.)
			Middle	Restin))Parinas Parinas)group Pale Greda)Salina Salina)group	*Clavilithes* series (Negritos)		
			Lower	Negritos	*Turritella* series (Negritos)		
MESOZOIC	Cretaceous		Upper	Monte Grande Copa Sombrero Pananga	Pananga limestone		
	Jurassic			Granite intrusion	Tablones group?		
Paleozoic	Pennsylvanian			Amotape slates and associated metamorphics	Amotape slates		

The oldest rocks whose ages have been definitely determined by fossil remains are certain Pennsylvanian slates and allied metamorphics. The metamorphism of these rocks is due to an intrusion of tourmaline granite which is probably of Jurassic age. Resting on the slates and granite at scattered localities are large and small remnants of Cretaceous limestones, shales, sandstones and conglomerates, and these in turn are followed by a thick and exceptionally complete section of Tertiary rocks of largely marine character. A thin section of Pleistocene deposits overlies these unconformably.

Nearly all of our work has been confined to a study of the structure and character of the Tertiary deposits on account of their economic importance as the source of petroleum. The observations which have been made regarding the older strata have been incidental to this work and as future studies are made of them there will undoubtedly be some additions and corrections made to the discussion given here.

PALEOZOIC

The Amotape Mountains, a spur off the main Andean range, are formed largely of slates, schists, quartzites, and other metamorphics. The same type of rocks form the Paita Mountains and the Silla de Paita as well as the Cerros de Illescas farther south. They are everywhere closely associated with a granite intrusion from which pegmatite stringers and quartz veins extend into the surrounding metamorphosed sediments. Close to the granite intrusion itself, this metamorphism has been carried to an extreme, forming typical mica schists which have led several observers to consider them as pre-Cambrian.

In the less metamorphosed types of the Amotape slates, fossil remains have been collected at several widely separated localities. These fossils include species of ***Productus***, ***Chonetes***, ***Ambocoelia***, ***Spirifer***, ***Spiriferina***, ***Orbicularia***, ***Aviculopecten***, ***Allorisma***, and others, definitely establishing their age as Pennsylvanian. Scattered joints of crinoids have been seen throughout a still larger area and it is believed that the Amotape slates and their associated metamorphics are largely of the same age.

MESOZOIC

The Mesozoic era, or group, is represented only by rocks belonging to the Cretaceous system. Bosworth mentions a Tablones group which he questionably referred to as Jurassic. It is believed that they are quartzites belonging in the Copa Sombrero formation.

CRETACEOUS

These rocks have not been studied in detail, although they are known to occur at several widely separated localities along the western base of the Amotape Mountains. In the basin of Quebrada Pazul, they extend for a distance of 8 or 10 miles back into the mountain area lying northeast of the Pananga fault. They also cover a large area in the upper part of the Chira valley, probably extending northeast into southern Ecuador. It is entirely possible that these outcrops are continuous with those exposed in the valley of Quebrada Pazul or at most only interrupted by a low range of older mountain rocks.

The following provisional subdivisions have been made of the Cretaceous rocks in this region: the Monte Grande, Copa Sombrero, and Pananga formations.

Pananga formation.—The Pananga formation consists mainly of hard, massive limestones, resting as a rule with a basal conglomerate on the Amotape slates. Two divisions are easily recognized by lithology and fossil content.

The lower part of the formation is a hard, massive, light-colored limestone. It is generally very fossiliferous. Species of *Nerinea* and *Actaeonella* are the most common and characteristic forms. These limestones are well exposed in a small erosional remnant at Pan de Azucar, a few miles north of La Brea, or still better in Quebrada Muerto and Quebrada Pazul in upper Parinas.

The lower Pananga limestones are followed by thin, well-bedded, dark, bituminous limestones which weather to a light gray color. They are best exposed in Quebrada Muerto, a branch of the upper Quebrada Parinas. They contain a different fauna from the lower limestones with a noteworthy absence of *Actaeonella* and *Nerinea*. A small amount of oil has been observed along the bedding planes and the rock itself is strongly bituminous.

Copa Sombrero formation.—This is by far the thickest and most widely distributed of the Cretaceous formations in this region. It consists largely of black shales, many carrying large limestone concretions, together with thin zones of cherts, hard sandstone layers, and even quartzites. These shales have not undergone as much metamorphism as the older slates of the Amotape Mountains, but are slightly more indurated than some of the dark Tertiary shales, many of which are difficult to distinguish lithologically.

Tests made to determine their oil content show that they are petroliferous, although no oil seepages have been found directly in connection with them.

Fossils are not plentiful in the Copa Sombrero shales. The limestone concretions contain large *Ammonites, Inoceramus,* and other forms. *Clavulina* are in places very plentiful in the shales.

The largest area thus far encountered in which the Copa Sombrero formation is exposed is located in the upper part of the Chira valley and east of the southern end of the Amotape Mountains. It is from their exposures about Copa Sombrero that the shales have received their name. The northern limit of the outcrop of the shales in this region has not been determined, but they are known to continue northward into southern Ecuador.

In the valley of Quebrada Pazul in upper Parinas, the Copa Sombrero shales cover a rather large area lying north and northeast of the Pananga fault. In this area, they may be seen resting on the upper Pananga limestones, and along their north edge are overlain by Tertiary sediments. They consist of several large bodies of black shales, along with interbedded seams of cherts and hard sandstones. They also contain several thick quartzites which are probably the rocks referred to by Bosworth in his Tablones formation.

Monte Grande formation.—The youngest Cretaceous rocks in this region consist of coarse conglomerates and sandstones to which the name Monte Grande formation may be applied. They have a very limited areal extent and are only found capping a few high hills near Quebrada Monte Grande, a tributary of Quebrada Parinas.

The Monte Grande rocks contain a very special fauna including rudistids and other peculiar pelecypods, among which species of *Roudairia* deserve special mention.

In their area, the Monte Grande sandstones may be seen resting on the Copa Sombrero shales or on the Amotape slates and beneath the middle Eocene.

CENOZOIC

Tertiary

The Tertiary deposits of this area are by far the most important from an economic viewpoint. They are the source of nearly the entire petroleum production of Peru.

These rocks have a total thickness of about 25,000 feet and underlie the entire coastal area from the base of the Andes Mountains to the coast, except in the small areas of the Paita Mountains and the Cerros de Illescas. They consist largely of the common types of shales, sandstones, and conglomerates deposited in moderately deep to shallow

marine waters. Limestones are generally rare and occur only as thin beds of local development.

The Tertiary section as described by Bosworth lacks much in the matter of detail and more recent work has shown that about 9,000 feet of sediments which he placed in the Eocene and Miocene should be referred to the Oligocene. Bosworth has given an accurate description of the lower and middle Eocene rocks under the name of the Negritos formation. More recent exploratory work has revealed 2,500 feet of sedimentary rocks in addition below the base of his section.

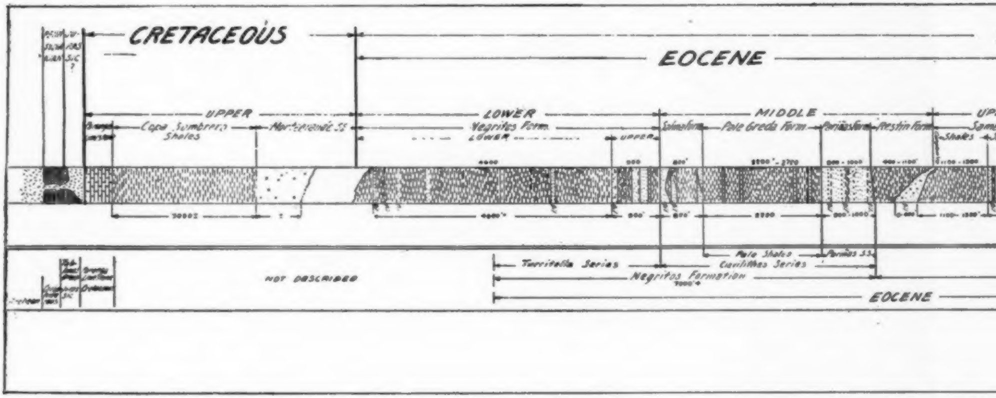
Bosworth's Negritos formation contains more than one paleontologic unit, and for this reason we have restricted this name to include only the beds of lower Eocene age or his *Turritella* beds, best exposed at Negritos itself. The Lobitos formation as defined by Bosworth has also, on extensive study, been further subdivided into seven distinct formations. These divisions of the Lobitos rocks are based on lithology and faunal differences, and their ages range from the upper middle Eocene to the upper Oligocene, and contain three unconformities of major importance. The Zorritos or Miocene rocks have also been further subdivided.

Pliocene rocks have recently been discovered south of the area studied by Bosworth. They should not be confused with the so-called Paita formation of Grzybowski, a name given to the true Pleistocene or Tablazo rocks above Paita.

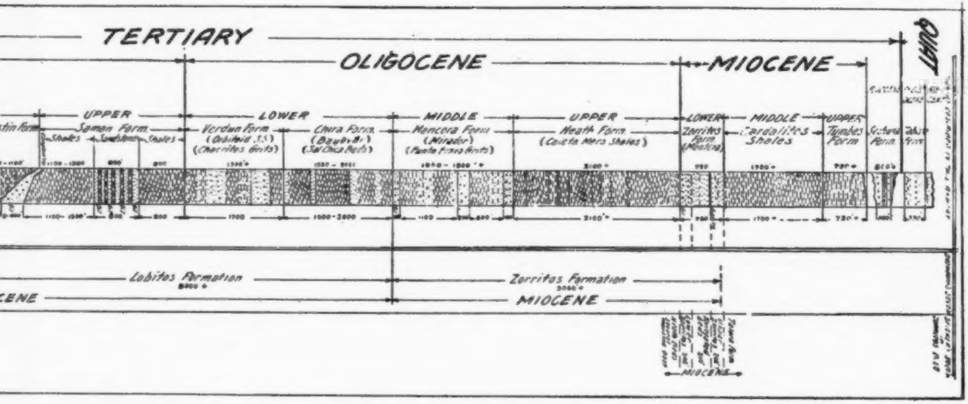
In order to facilitate a comparison of the section used in this paper and that of Bosworth, his classification is shown on the accompanying table (Table I) and on the generalized columnar section (Plate 1). Spieker's Zorritos section is also given.

Eocene.—Approximately one-half of the Tertiary deposits of northwestern Peru are Eocene in age. They have their greatest development in the vicinity of Negritos, but they are also found exposed as far south as the Cerros de Illescas and as far north as Tumbes River. Another large area in which they are exposed is in the Chira valley. In the Negritos region, they occur from the coast inland to the base of the Amotape Mountains.

The Eocene rocks consist primarily of shales, sandstones, and conglomerates, and it is from these beds that the greater part of Peruvian petroleum is obtained. Because of their marine and near-shore origin, many of the formations are very fossiliferous and their classification and divisions have been based on a close study of their paleontological characteristics. They may be divided into three primary divisions,



Generalized columnar section of



r section of northwest Peru.

equivalent to the lower, middle, and upper Eocene as these terms are generally understood in the classification of the Eocene rocks of the coastal plain area of the southern United States.

LOWER EOCENE.—*Negritos formation.*—As previously stated, this name is restricted to include only the *Turritella* beds of Bosworth's section. They are typically developed only at Negritos and have an exposed thickness of about 1,500 feet, but drilling has revealed 4,000 feet additional and the base of the formation has not yet been encountered.

The formation consists of thin-bedded sandstones and pebble seams, with thicker beds of fairly hard, dark gray or blue shales. The pebble beds are lenticular and some cross-bedding is apparent. Glauconite is of common occurrence at some horizons. Fossils are very plentiful in the upper part of the formations but comparatively rare in the lower part. Because of this feature, as well as lithological differences, the formation has been divided primarily for field purposes into an upper and a lower member.

The Negritos formation contains a very characteristic fossil fauna which has been fully described and figured by Woods in Bosworth's *Geology and Paleontology of Northwest Peru.* It is specially characterized by several species of large *Turritella*, varietal forms of *Venericardia planicosta*, *Leda ingens* Woods, and a curious *Calyptraphorus* type of gastropod described by Douville as *Aulacodiscus lessonii.*

The Negritos formation contains several oil sands and it was from these beds that the first commercial production was obtained in the coastal area. One of these sands, known locally as the "36-foot" sand, is near the base of the upper member of the formation. Another sand, known as the "Main sand," is about 2,000 feet below the top of the formation. Sporadic production has been secured from thin lenticular sands throughout the same part of this formation. More recent development has revealed the presence of additional sands from 4,900 to 5,400 feet below the top and there is a possibility of additional sands farther down, as this represents the maximum depth to which the formation has been penetrated.

Outside of the Negritos district, the only other known locality having exposures of the Negritos formation is a small area in the La Brea district at the base of the Amotape Mountains. The beds are brought to the surface by faulting and folding and are of more sandy character than at Negritos. Their identity is established by their

characteristic fossils. Some oil is secured from these rocks in this region also.

Middle Eocene.—The *Clavilithes* beds of Bosworth's section and part of his Lobitos formation are considered as belonging to the middle Eocene. In the Negritos district, these rocks have a combined thickness of fully 4,900 feet and are completely exposed in several large fault blocks. They may be divided as follows:

Classification of Middle Eocene

SUPER-FORMATION GROUP	FORMATION	BOSWORTH'S CLASSIFICATION
Parinas	Restin	Lower part of Lobitos
	Parinas	
Salina	Pale Greda Salina	*Clavilithes* series

Salina formation.—This formation has a thickness of about 800 feet and consists of alternating sandstones, shales, and pebble beds. The characters of the sediments are much the same as in the upper part of the Negritos formation, and the rocks must be wholly distinguished by their fossil differences.

The base of this formation is generally marked by a conglomerate or a series of conglomeratic lenses. Because of the very sudden change in the fauna, this horizon probably marks an unconformity and its constant character wherever these rocks are exposed deserves special mention.

In common with the upper part of the Negritos formations, the Salina rocks are plentifully fossiliferous. They are at once recognized by the introduction of several new forms and the lack of the characteristic Negritos species. Certain of these key fossils form the dominant elements in the fauna, in many places to the exclusion of the longer-ranging species.

The following species appear for the first time in the Salina beds, but may continue into higher rocks: *Turritella anceps* Woods, several species of *Clavilithes*, varietal forms of *Volutospina peruviana* Woods, varietal forms of *Venericardia planicosta* Lam., and others.

This formation outcrops in several fault block structures east and southeast of Negritos. As it borders the Salina in several places, this name has been applied to it.

Some production has been secured from this formation, but it is of

irregular occurrence due to the lenticular character of its sandy horizons.

Pale Greda formation.—The thickness of this formation ranges from 2,000 to 2,700 feet. It consists largely of light gray or dirty-yellow-weathering shales lying between the sandy Salina beds and the overlying Parinas sandstones. It carries several thin sandstone members found principally near the top and base of the formation. Thin seams of limestones with well developed cone-in-cone structure occur at several horizons, together with hollow gypsiferous concretions, particularly near the base. There are a few local seams of pebble beds developed here and there, of special importance, as they are generally fossiliferous. The cone-in-cone limestones are nowhere more than a few inches in thickness and are similar to those in the higher Restin shales.

The Pale Greda beds are best exposed in the area east of Negritos and west of the Keswick Hills, where their full thickness may be observed. They have also been brought to the surface by faulting in the Verdun district about three miles north of Lagunitos. They are also exposed in the vicinity of Restin and Cabo Blanco about 30 miles north of Negritos, but their thickness in this area is apparently very much less.

Although here and there a thin, oil-bearing sand has been encountered in this formation, no production of note has ever been found.

Parinas formation.—The Parinas sandstone is one of the most easily recognized of the Tertiary formations in the Negritos district. This is due mainly to its lithology, although its fossil characteristics are also quite distinctive. In the Negritos district, it has a thickness ranging from 900 to 1,000 feet and consists almost entirely of sandstones and conglomerates, although many thin, irregular beds of shale are present.

The sands vary from medium-grained to coarse and are interbedded with zones of conglomerates. In these zones the pebbles have an average diameter of less than two inches, and are largely of quartzitic character. Where thin shale members are present, these may range in color from black to blue, green, or light pink.

Silicified wood is a common and characteristic feature of the Parinas sandstone, and the name of Arbol sandstone was formerly applied to these rocks on this account. It is not uncommon to find well-preserved tree trunks fully 18 inches in diameter and more than 20 feet in length.

The Parinas sandstone, although mainly sand and conglomerate, is largely of marine character and fossil zones are plentiful, especially in the lower part of the formation. They include most of the species characteristic of the *Clavilithes* beds, but in addition, several special species may be noted: *Turritella*, particularly *T. annectans* Woods

(also in the Restin), *Morgania magna* Woods, a peculiar species of *Carolia*, and *Melina* (*Perna*) *arbolensis* Woods. The fossil wood so common in the Parinas is generally filled with *Teredo* tubes, proving that it has drifted or been stranded in marine waters.

The sands of which this formation is composed have been rather firmly cemented, with the result that they resist erosion to a far greater degree than the bordering formations, and its outcrop is generally marked by hills or ridges.

The Parinas sandstone has been named from its outcrop at Parinas Point, the westernmost point of South America. At this exposure, wave erosion has developed a low sea cliff where the general character of the formation may be well observed. It may also be seen at Punta Balcones, a point on the coast about one mile south of Parinas Point.

North of Negritos, the Parinas sandstones form the high sea cliffs for a distance of 3½ miles toward Talara. Other prominent outcrop areas are the Keswick Hills between 2½ and 3 miles east of Negritos, as well as the Yerba Blanca about 3 miles southeast of Negritos. Many ridges of this sandstone are faulted up through younger formations, north of Lagunitos in the lower Verdun district.

The Parinas sandstones outcrop throughout a large area north of La Brea and continue northward along the base of the Amotape Mountains, in many places resting directly on the older mountain rocks. The formation has a greater thickness in this area, probably due to its being closer to the source from which its materials were derived.

The most northerly point where the Parinas sandstones have been identified, is at Restin and Cabo Blanco, about thirty miles north of Negritos. In this region, these rocks are known locally as the Cabo Blanco sandstones and have a thickness of only a few hundred feet. They are conspicuously exposed in several small fault blocks along the face of the high escarpment bordering the coast from Restin to Cabo Verde. Here one's attention is immediately attracted to them on account of their brilliant white color, mottled or variegated with pink and yellow. Cabo Blanco, a prominent and well known point on the coast, has received its name from the exposures of these sandstones.

The Parinas formation is one of the chief sources of petroleum production in the coastal area. Production is secured from it in practically all of the districts connected with the Negritos fields except at La Brea. There are three zones from which the major part of its production is derived. One of these is near the top, another near the middle, and the other near the base.

Restin formation.—The type locality for this formation is Restin, a small oil field controlled by the Lobitos Oil Fields Ltd., about 30 miles north of Negritos. At this locality the formation is formed largely of dark gray to green-colored sandstones and shales, very fossiliferous. Traced toward the north, the rocks become more sandy and conglomeratic, and largely lose their marine character, while a transition to shales is evident toward the south.

In the region north of the Mancora valley, the Restin formation is much thicker and more sandy and conglomeratic. Its outcrop in this area extends from the Mancora valley northward to Rica Playa in the upper Tumbes valley, and is fairly well limited to the eastern portion of the coastal area. In this region, these rocks, consisting mainly of coarse sandstones and conglomerates, form the basement portion of the Tertiary section, and along the base of the Amotape Mountains may be observed resting on the pre-Tertiary rocks. In the upper part the beds are sparingly fossiliferous with common Restin species.

South of Restin, these rocks are again exposed near Lobitos as massive, concretionary sandstones with interbedded shales. They form a small coastal point known locally as Punta Nautilus, so named because of the relative abundance of a large nautiloid, named *Hercoglossa peruviana* by Berry.

The next appearance of this formation at the south is in the center of the Jabonillal uplift in the lower part of the Parinas valley. In this area the beds have retained much of their sandy character and are very fossiliferous. They also outcrop with similar lithology a few miles farther east, lying over the Parinas sandstones along the foot of the mountains.

From Jabonillal southward to Talara, the Restin is covered by younger formations. From Talara southward, the formation differs considerably from its northern phase in that the sandy character has graded laterally into shales. A few lenses of sands and even thin conglomerate and limestone are present. These limestones have the cone-in-cone structure similar to those of the Pale Greda.

The lower shales in the Negritos and Talara districts generally weather to a light yellow or gray color. In many places at their base they are very fossiliferous and the thin sandstones above contain fossil palm nuts and fragments of silicified wood. The upper Restin shales are darker in color, with a green tint predominating, and seamed with yellow-brown layers of cone-in-cone limestones. The smaller forms of *Foraminifera* are plentiful at most horizons.

The fossils of the Restin formation contain many species which have continued up from the underlying beds, and show close relationship with those of the Parinas sandstones. They also contain several new species such as special species of *Turritella*, oysters, special varietal forms of *Venericardia planicosta* Lamarck, a new species of *Carolia*, various echinoids, and corals.

The thickness of this formation in the general Negritos area ranges from 400 to 1,100 feet, the difference being due to an erosional unconformity at its top. In this portion of the area, good exposures may be found east of the Keswick Hills, where the formation overlies directly the Parinas sandstones. Beds are also exposed along the Talara-Negritos railway, where their stratigraphic relations with the Parinas sandstones and with the overlying Saman are well displayed. The lower part of the section may also be seen at Punta Parinas and Punta Balcones, the latter locality marking the southernmost outcrop of the formation known.

The Restin appears to be one of the important formations from which the petroleum of this region was originally derived, as it directly overlies and underlies two of the best producing sands in the Negritos field.

UPPER EOCENE.—The close of middle Eocene deposition was followed by important earth movements resulting in elevation and erosion of the coastal area. On renewed sedimentation, the incoming upper Eocene sea transgressed widely and in some regions far beyond the former limits of Tertiary rocks. The unconformity at the base of the upper Eocene rocks therefore marks one of the most important stratigraphic breaks in the entire Peruvian Tertiary section. The upper Eocene also brought the introduction of a new marine fauna which continued in a modified form into the Oligocene.

The upper Eocene rocks are grouped in the Saman formation, and in the Negritos area the following subdivisions have been recognized: the Saman conglomerate, the Saman shales, the Saman or Talara sandstones and the Pozo shales.

Saman formation.—The Saman formation overlies the Restin rocks unconformably. In many localities, the base or the lower part of the Saman is represented by massive, coarse conglomerates and sandstones, or by a series of alternating sandstones, shales, and pebble beds. In many places no sandy beds are developed and the base and lower part of the Saman rocks are entirely shales. In places where sandy beds and conglomerates are developed, they are generally referred to as the

Saman conglomerate and in many sections of the field are a very important oil horizon.

The best exposure for the study of the character of the Saman conglomerate is about 1½ miles southeast of Negritos, where it has been faulted down into contact with the older Negritos formation. At this locality the beds are about 200 feet thick and they are mainly formed of very coarse conglomerates, with interbedded coarse sands and shales.

The outcrop of the base of the Saman rocks or the horizon of the Saman conglomerate may be observed to follow the upper edge of the Restin rocks from east of Negritos northward to Talara. The conglomeratic phase along this line of outcrop is generally thin and as a rule limited to a few lines of large cobbles, closely associated with zones of glauconite and fossiliferous sandstones. Farther east the Saman conglomerate has been identified in wells in the eastern part of the Lomitos district, reaching a maximum thickness of about 400 feet.

The base of the Saman formation or the horizon of the Saman conglomerate contains a fauna by which it may be readily distinguished. Its most characteristic key fossils include *Orthophragmina peruviana* Cushman, a small highly sculptured nummulite which is mainly confined to this horizon, several species of mollusks, and echinoids. They also include the only brachiopod so far known from the Peruvian Tertiary, which is very plentiful in many places and limited to this horizon.

The Saman conglomerate is an important oil horizon in the Negritos field. It is productive in the lower Verdun, Lagunitos, and in parts of the Lomitos districts.

Saman shales.—The lower half of the Saman formation largely consists of dark gray or black, well-bedded shales which weather to a dull brown color. They are readily distinguished from the Restin shales by the intervening Saman conglomerate and by their difference in color. In the Negritos region, they are more than 1,100 feet thick.

In some localities, a conglomerate or sandstone horizon distinct from the Saman conglomerate lies about 500 feet above the base of the Saman formation. This horizon is neither uniform nor continuous.

In the Lagunitos region and in the eastern part of the Lomitos field, the Saman shales become increasingly sandy. These sandstones are gritty and generally contain many orbitoidal *Foraminifera*. They are for this reason usually referred to as the orbitoid beds. They have produced some oil.

Saman (*Talara*) *sandstones and Pozo shales.*—In the northern part of the Negritos region, the upper part of the Saman formation is conveniently divided into two members, termed the Saman or Talara sandstones and the Pozo shales.

The Saman sandstones, typically developed at Talara, consist of well-bedded flaggy sandstones, separated by thin beds of shale. They show considerable lateral variation, changing on one hand to thin, papery sandstones and sandy shales; on the other, to massive, hard, concretionary sandstones. Coarse, heavy conglomerates are locally developed, as, for instance, near Jabonillal. On weathering, the Talara sandstones assume a dark color which gives a characteristic appearance to their outcrop. Their thickness ranges from 400 to 800 feet, according to locality. They are generally unfossiliferous or contain only scattered *Operculina* and nummulitic *Foraminifera*.

The Saman sandstones grade upward into well-bedded, hard greenish shales termed the Pozo shales. In lithology, these shales resemble closely the shales interbedded with the Saman sandstones and where freshly exposed have a greenish tint. They generally contain thin seams of hematite and limonite as well as thin papery sandstone layers. Their thickness ranges from about 200 feet to more than 800 feet and, like the Saman sandstones, they are very sparingly fossiliferous.

In the Lagunitos district, the Saman formation differs considerably from the equivalent beds on the north and the divisions previously described are no longer recognizable. Its lower part consists mainly of typical Saman shales interbedded with lenticular orbitoidal sands. Toward the top is a coarse gritty sandstone, known as the Lagunitos sandstone. It is best exposed in and near the village of Lagunitos and locally may be fossiliferous. It contains nummulitic *Foraminifera* and species common in the upper Saman, as *Telescopium peruviana* Woods, and *Cerithium*.

North of the Negritos region, the Saman rocks continue as a broad belt northward along the inner edge of the Tertiary to, and possibly beyond, Tumbes River. Their general occurrence is as black shales some of which may resemble the black Cretaceous shales of the Copa Sombrero formation. They are associated with zones of flaggy sandstones, grits, and conglomerates, and more rarely hard limestones. These rocks may be very fossiliferous and the characteristic Saman species have been collected over a wide area.

An interesting feature of the Saman rocks in the northern area is the occurrence of hard, yellow, *Lithothamium* limestones in the base

of the formation. These limestones are lenticular masses of reef origin and contain fossils characteristic of the horizon of the Saman conglomerate.

The Saman formation also outcrops extensively in the Chira valley, where it occurs mainly as yellow concretionary sandstones with interbedded shales. They are particularly well developed at Casa Saman near Sullana, and it is from this locality that the formation has received its name. The typical Saman sandstones are extremely fossiliferous.

The true Saman sandstones of the Chira valley are also exposed at Paita, where they rest on the mountain rocks along the north and west sides of the Paita Mountains. They occur with very similar lithology but with heavy orbitoidal limestones near the base around the edges of the Cerros de Illescas. At this locality, also, they form the basal Tertiary rocks.

The Saman formation is very fossiliferous in many places and its fauna is mainly different from that of the earlier Eocene rocks. Of particular interest is the introduction for the first time in the Peruvian Tertiary section of nummulitic and orbitoidal *Foraminifera*, and these continue upward into the overlying Oligocene rocks. Its fauna also includes a large list of mollusks, echinoids, and corals, many of which likewise continue into the overlying beds. The upper Eocene age of the Saman rocks is demonstrated by the presence of species of *Orthophragmina*, the last appearance of *Venericardia planicosta* Lamarck, the brachiopod *Liothyrina*, closely allied to the species from the upper Eocene rocks of Trinidad and St. Bartholomew, certain characteristic echinoids and several mollusks.

Production of petroleum is obtained from many horizons in the Saman formation of which the Saman conglomerate and the orbitoid beds have already been mentioned. Production is also secured from the Talara and Lagunitos sandstones higher in the section.

Oligocene.—Lying above the Saman rocks, definitely determined as upper Eocene, and below the Zorritos Miocene is a thick series of shales, sandstones, and conglomerates. These rocks belong to the Oligocene series, and have a thickness of more than 7,000 feet. They are exposed in a large area extending from the Cerros de Illescas in the south northward nearly to Tumbes River, where they disappear under an overlap of the Miocene. On the basis of faunal succession and stratigraphy, they are here divided into three major divisions, which may be roughly referred to the lower, middle, and upper Oligocene. The classification adopted here is as follows:

Classification of Oligocene

Upper Oligocene	Heath formation
Middle Oligocene	Mancora formation (Punta Bravo grits)
Lower Oligocene	Chira formation (Bayovar formation) (Verdun formation)

It has not been possible for us to recognize the Ovibio formation of Grzybowski, referred by him, without any definite paleontological data, to the Oligocene. This locality is not shown on any of our maps nor have we heard of it during our exploration work. The locality may possibly be the Oidor in the middle Tumbes valley, in which case the rocks are Miocene.

Lower Oligocene.—*Verdun formation.*—This formation is most extensive in the area adjoining the Parinas valley, north of Talara. It also outcrops in a wide belt along the northern flank of the Negritos structure, centering about High Verdun, from which the formation derives its name.

In their most typical development, the Verdun rocks consist of massive, gritty, orbitoidal sandstones and somewhat gypsiferous shales. In the region north of Negritos, and particularly along the Parinas valley, lithological units have been recognized during detailed field mapping. They consist of three grits and three shale members and have a combined thickness of more than 2,000 feet.

The base of the Verdun rocks may be observed at several localities, overlying the Pozo shales. It is generally represented by gritty sandstones ranging in thickness from a few inches to more than 200 feet. This horizon may represent an unconformity as boulders containing Restin and Saman fossils have been collected in a few localities. The difference in thickness of the underlying Pozo shales, even in short distances, is additional evidence for an erosional unconformity at the base of the Verdun rocks.

The character of the Verdun formation as found in the vicinity of the Parinas valley continues as far north as Lobitos and Restin. In the region north of the Mancora valley, the equivalents of the Verdun rocks are heavy, massive, or flaggy sandstones, in many places associated with very coarse conglomerates and gray-green shales. The conglomerates which occur either near the base or in the top are often very coarse, with cobbles of granite, slate, and quartzite derived from the

old mountain rocks. They also contain boulders and rolled fossils of Restin age. These conglomerates and their associated sandstones are everywhere well cemented and their outcrop gives rise to high rugged hills and ridges, whose elevation may be more than 1,400 feet. They form the high hills of Cerro de Pinal, Canoas, and the Tunal Hills, the latter just south of the Mancora valley.

Orbitoidal *Foraminifera*, generally belonging to the genus *Lepidocyclina*, are very plentiful in the Verdun rocks and include several species. With the exception of a large heavy-shelled oyster and a few mollusks of very local occurrence, fossils are absent or represented only by reworked specimens derived from the Restin and Saman formations.

South of Lagunitos, the Verdun formation is represented by a great thickness of shales, containing only minor beds of grits or sandstones. These rocks are closely associated with the Chira shales, from which they can not be readily distinguished. They have therefore not been differentiated throughout a large area.

A small amount of oil has been produced from the Verdun rocks in the Negritos field.

Chira formation.—This formation is composed mainly of black, bituminous, foraminiferal shales weathering to a dull brown or reddish-brown color. These shales outcrop widely through the Chira valley, forming high conspicuous cliff faces below the Tablazo limestones, as near Vichayal and Amotape, and east and northeast of Paita. Many of them contain striking white bands of volcanic ash, or bentonite, and a few thin beds of impure fuller's earth. Where the shales have been broken down by weathering, they become highly gypsiferous and many of their fossils are completely replaced by gypsum.

Sandstones occur at several horizons in the Chira shales, the most persistent being near the top of the formation. These sandstones are generally very hard and blocky in character, and become progressively thicker and more important as they are traced toward the east. They are strongly clastic, their main ingredients being fragments of volcanic ash and tuffs.

In the Chira valley fossils are not common in the Chira shales except at a few widely separated localities. In addition to a few species which have continued up from the Saman rocks, a large number of new forms have appeared, many of which are limited to this formation. Very characteristic of the Chira shales are zones of nummulitic sandstones and limestones, and the shales themselves are generally very rich in the smaller forms of *Foraminifera*.

In the northern part of the coastal region, the Chira formation occurs in a wide area north of the Mancora valley. In this region, the shales may be very similar to those found in the Chira valley, or they may be sandy, glauconitic, or even calcareous. They are generally more fossiliferous than those farther south. Sandstones and limestones crowded with the packed tests of *Nummulites* are a common feature.

South of the Chira valley, the equivalents of the Chira shales have been identified around the margins of the Cerros de Illescas, resting on the Saman sandstones. They consist of foraminiferal tuffaceous shales and sandstones in which zones of *Nummulites* have been noticed. The Chira formation has a thickness ranging from 1,500 to 2,000 feet.

MIDDLE OLIGOCENE.—*Mancora formation.*—This formation is essentially a series of sandstones and conglomerates, in many places somewhat lignitic and deposited under truly marine or brackish-water conditions. Its type exposures are near the villages of Mancora Grande and Mancora Chica, about 40 miles north of Negritos.

As its type locality, the Mancora formation has a thickness of 1,000 or 1,500 feet and is made up primarily of coarse, massive and well-bedded sandstones, grits, and conglomerates, with some chocolate shales. In places the color of the sands is rather brilliant and varicolored, including pure white, yellow, brown, red, and green. The rocks are highly micaceous and on lithologic grounds resemble the variegated beds of the Zorritos Miocene and to a lesser degree the Cabo Blanco sandstones of the middle Eocene. At Mancora, the fossils are mainly of marine origin.

The Mancora rocks continue northward along the coast, gradually swinging inland toward the middle portion of the Tumbes river valley. They are particularly well developed from Punta Bravo northward to Punta Mero and inland, crossing the Quebrada Boca Pan just north of Trigal. Along this line of outcrop, the rocks consist of brilliant white and varicolored grits, with interbedded conglomerates and red and green shales. These rocks are mainly of brackish-water origin and contain several species of brackish and fresh-water gastropods, such as *Pleurocera* and *Ampullinopsis*.

South of Negritos, the Mancora rocks are exposed also at Lagunitos, from which point they continue east and south throughout most of the Chira valley. At Lagunitos, the formation is largely gypsiferous shales with only minor beds of black cobble conglomerates. They contain the same fossils as the more typical beds to the north.

In the Chira valley, the Mancora rocks are generally rather sandy and conglomeratic, although the formation still shows considerable lateral variation. A very coarse conglomerate composed mainly of rather large black cobbles of igneous rocks occurs at Punta Mirador near the mouth of Chira River. This conglomerate continues up the Chira valley and contains fossils similar to those found in the Punta Bravo grits.

In most localities, the Mancora rocks are believed to rest unconformably on the underlying Chira or older beds. This stratigraphic break is generally indicated by the abrupt change in deposition from highly marine shales to sands and conglomerates of brackish- or even fresh-water origin. The conglomerates may contain rounded fossiliferous boulders derived from the Chira and Saman formations, together with re-worked fossils from these same formations. In the northern area the Mancora rocks progressively overlap on the older beds as they are traced to the north, until in the valley of Quebrada Boca Pan, they rest upon the Saman and Restin formations.

This formation is not a source of petroleum except in the vicinity of Lagunitos, where some oil is obtained in the conglomeratic zones. In such cases, it is believed that the oil has migrated into these beds from the older rocks with which they lie in fault contact.

UPPER OLIGOCENE.—*Heath formation.*—This formation is composed mainly of shales lying directly beneath the Zorritos Miocene and above the sands and conglomerates of the Mancora formation. They were first named the Heath beds by Grzybowski, from their typical exposures in Quebrada Heath in the Zorritos region and referred to the lower Miocene.

The Heath beds consist primarily of black, bituminous shales generally rich in the smaller types of *Foraminifera*. They may contain a few thin seams of sandstones in their upper part with irregular lenses of black-pebbled conglomerates. On weathering they assume a dirty brown or chocolate color and become strongly gypsiferous. Many of their fresh exposures are covered with a thin saline deposit of alum and yellow precipitates, and all waters issuing from them are very strongly alkaline. They may contain very large, yellow, cherty limestone concretions in some of which fossils may be found.

Toward the base, the Heath shales pass gradually into the upper part of the Mancora formation, so that the boundary between the two formations must be placed arbitrarily. Similarly, in the Zorritos region the top of the Heath beds apparently grades upward into the lower

Zorritos Miocene, but elsewhere there is strong evidence that they underlie the Miocene unconformably.

South of Zorritos the Heath beds are typically developed in the area between Piedra Redonda and Punta Mero and again farther south just north of Mancora.

In the region between Lagunitos and the Chira valley the Heath formation outcrops in a large synclinal area. In this district the formation appears to attain a thickness of about 3,000 feet. The lower 2,000 feet of this section is composed mainly of gray shales with concretionary and bedded yellow and gray limestones. Many of these limestones are cherty and contain fossils in which species of *Phacoides* and other lucinoid genera are most common.

The Heath formation continues south throughout a large area in the Chira valley, where it has generally been called the Cone Hill shales. These resemble their equivalent beds in the north, but also contain thin, red-weathering platy sandstones in their lower part.

In the northern region, the sands or conglomeratic layers occurring in the upper part of the Heath formation are the source of much of the petroleum production in the Zorritos oil fields.

Miocene.—Rocks of Miocene age have been known in the coastal area of northern Peru for a great many years. Fossils from the Zorritos region were first described by Nelson in 1870, who referred them to the later Tertiary. Additional species were described by Grzybowski in 1899, and a few others, collected by Bosworth, were noted by Woods in 1922. A fuller account of the Zorritos region and its fauna, by Spieker, appeared in 1922, and to this particularly the reader is referred.

The Miocene fauna of northern Peru is similar in most respects to the Miocene of Central America and the Caribbean region. They contain many species in common. The typical Zorritos fauna is considered as lower Miocene, or in terms of the European time scale, the Burdigalien.

Miocene rocks have recently been discovered along the east side of the Cerros de Illescas, where they are brought into contact with the old mountain rocks through faulting.

In the northern area, the southern limits of the true Miocene rocks lie at Piedra Redonda, about 18 miles south of Zorritos. On Bosworth's map they are shown as extending south to Punta Bravo, a mistake due to miscorrelation of the Punta Bravo grits, which rightfully belong to the Mancora formation. From Piedra Redonda, they continue north and northeast to Tumbes River and beyond into Ecuador.

At Piedra Redonda and in the Zorritos region, they rest on the Heath shales, but farther east they overlap widely on the older beds.

In the northern area, the Peruvian Miocene may provisionally be divided into three major units or formations as follows:

Classification of Miocene

Upper Miocene	Tumbes formation (Mainly sandstones, conglomerates, and ash beds)
Middle Miocene	Cardalitos formation (Mainly black bituminous shales)
Lower Miocene	Zorritos formation (Sandstones, conglomerates, shales, highly fossiliferous)

Lower Miocene.—*Zorritos formation.*—This formation, representing the lower part of the Peruvian Miocene, was named by Grzybowski from its type exposures at Zorritos. Its fossil fauna is fairly well known, and for a full account the reader is referred to Spieker's work published in the Johns Hopkins University Studies in Geology, which appeared in 1922. Spieker has divided the Zorritos rocks into three divisions, based on lithology and faunal differences.

The lower Zorritos is given a thickness of about 245 feet. Its basal part consists of thin-bedded, light-colored sandstones, interbedded with chocolate-colored shales which grade downward into the upper Heath beds. Above these transitional beds, the rocks become massive sandstones, containing pebbles and lenses of conglomerates. These rocks are generally yellow, although some are stained with red. Locally they may be very fossiliferous. A few are lignitic and thin beds of shales may be scattered throughout.

The middle Zorritos is represented by a very conspicuous series of rocks known as the Variegated beds. They are especially well exposed in the coast region west of Zorritos behind the village of Boca Pan toward Punta Picos. The rocks consist mainly of sandy shales, colored gray, red, green, or purple, and are interbedded with yellow sandstones, dark colored conglomerates and lignites. They are generally much broken by faults or interformational deformation, and are estimated to be about 300 feet in thickness.

The upper Zorritos rocks are similar in most respects to the lower. They are mainly yellow, massive sandstones many of which contain

large cannon-ball concretions and scattered layers of shales. Their thickness is about 200 feet.

In the Zorritos region, the lower part of the Zorritos formation is productive of petroleum.

Middle Miocene.—*Cardalitos formation.*—In certain localities, the upper Zorritos sandstones are overlain by black, bituminous shales which resemble closely the underlying shales of the Heath formation. In Grzybowski and Spieker's sections, they are referred to the Talara formation, a name proposed by Grzybowski for the shales exposed in the vicinity of Talara, and believed by him to belong to the upper Miocene.[1] As the Talara shales are entirely of Eocene age, this name can not be used for the Miocene rocks. For the Miocene shales we propose the name of the Cardalitos formation, the name being taken from one of the larger Quebradas in this section. The Cardalitos shales have a wide area of outcrop between Punta Picos and Piedra Redonda, and in smaller areas north of Zorritos.

The Cardalitos formation is essentially shale. It contains thin layers of sand and limonite beds in its lower part, giving a rusty appearance to the weathered outcrop. Above, the beds pass abruptly into black bituminous shales with yellow limestone concretions, and much gypsum, and by straight lithology can not be distinguished from the Heath beds. Gypsum in the form of curious arrowheads is found, and these are similar to those of the Heath and Mancora beds.

No fossils, except the smaller types of *Foraminifera*, have been found in the Cardalitos shales and their reference to the middle Mio-

[1]The reconnaissance of Grzybowski began at Paita. In 1870 Gabb had described a few fossils collected by Orton and Ramondi at Paita. This fauna contained, along with several recent species, several new species, and because of this association Gabb suggested that the beds were probably of Pliocene age, although he also noted that the matrix covering the fossils varied somewhat in character as if the fossils might have come from different beds. It has since been found that this was a mixed fauna, collected from rocks of very different ages. The recent species were derived from the Pleistocene Tablazo limestones, the few of the extinct species from the Saman sandstones of the upper Eocene. In the western part of the town of Paita, the Saman sandstones directly underlie the Tablazo limestones, with which they are easily confused.

Probably guided by Gabb's determination, Grzybowski believed the Tablazo rocks to be Pliocene and he gave them the name of the Paita formation. East of Paita, they overlie the Chira shales, which, from lack of other evidence, were considered as upper Miocene. North of Talara, the shales below the Tablazo beds were believed the equivalent of the shales at Paita, and the name of Talara formations was applied to them. Grzybowski's name therefore covers shales exposed at Paita and Talara, of middle-upper Eocene and lower Oligocene age. At Talara, it cannot be determined which shales he had in mind, and his name is therefore not accepted in this paper.

cene is based on stratigraphic relations. Their total thickness has not been determined, but it is probably in excess of 1,700 feet.

UPPER MIOCENE.—*Tumbes formation.*—Miocene rocks outcrop in the entire area east and northeast of Zorritos and for several miles up Tumbes River. In the lower courses of the Tumbes valley, they consist mainly of coarse sandstones and conglomerates with interbedded volcanic tuffs. These rocks are generally unfossiliferous or contain only a few oysters and more rarely specimens of a large *Arca*, allied to *Arca grandis* Brod. and Sow. They are provisionally placed in the upper Miocene.

In the Sechura Desert, Miocene rocks have been found along the coast east of Bayovar and inland for a short distance along the east side of the Cerros de Illescas. In this locality they are mainly yellow sandstones, arenaceous limestones, together with beds of diatomaceous earth. They are generally very fossiliferous and are the equivalent of the Zorritos formation of the northern coastal area. Their exposed thickness is about 750 feet.

PLIOCENE.—Rocks which have been referred to the Pliocene occur only in the southern part of this region. They probably underlie the greater part of the Sechura Desert south of Chira River and for this reason may be termed the Sechura formation.

Sechura formation.—This formation probably underlies the greater part of the Sechura Desert south of Chira River. As a rule, it lies buried under a blanket of Pleistocene Tablazo beds or more recent deposits, but in places it is exposed in the deeper cuts. Its bedding is generally horizontal or nearly so, and in places may be difficult to distinguish from Tablazo deposits. The formation occurs in two phases, a coastal phase consisting of conglomerates or shore limestones and a deeper-water phase represented by marls, clays, and diatomaceous earth.

A heavy coarse conglomerate occurs along Chira River at Sullana and the same beds occur also along Piura River north and east of Piura. These conglomerates belong to the coastal phase of the Sechura formation.

Along the east side of the Cerros de Illescas, the Sechura formation occurs as hard, massive, sandy limestones, lying unconformably over the Miocene. A conglomerate may be present carrying pebbles of granite, quartz, mica-schist and slates, and a few pebbles of the same rocks may be scattered through the limestones. Fossils are rather plentiful and include a large *Turritella*, a *Macrocallista*, and *Dosinia grandis* Nelson (*D. ponderosa* Gray).

As the coastal limestones and their associated conglomerates are traced eastward out into the desert, they are gradually replaced by light-colored clays, sands, and marls which were deposited in deeper and quieter waters. Moderately thick beds of diatomaceous earth are found in some localities, with darker colored clays filled with fish remains. Where these rocks are well exposed they form steep or nearly vertical slopes or occur as isolated butte-like hills, capped with a small remnant of Tablazo. These deeper-water clays are well exposed in the Cerros de Ahorcado west of Piura, and in the deep Salinas east of Bayovar.

The deeper-water clays contain much gypsum, which is locally gathered for commercial purposes. Small nodules of psilomelane are also generally found in these clays. Fossil remains, such as scales and teeth, are plentiful, and large specimens of carcharodon shark teeth have been collected near Piura in the Cerros de Ahorcado. At this locality, imperfect skeletons of whales are fairly common, the bones generally replaced by gypsum.

The formation may attain a thickness of as much as 800 feet.

Quaternary

Pleistocene.—Deposits of Pleistocene age in this area consist of shell limestones containing pebbles, marls, conglomerates, calcareous sandstone, and a small amount of varicolored shale. These deposits are chiefly white to yellowish-white in color. The degree of cementation is variable, so that the mode of weathering is different in different localities. In some places steep cliffs are formed and the limestones break off in large masses, whereas at other places, the material breaks down very easily and gentle slopes result. The surface is generally covered by a bed of gravel whose thickness ranges from a few inches to several feet. The pebbles found in this formation range in size from very small ones to some more than a foot in diameter and consist of quartzites, slates, and several types of igneous rocks derived from the Amotape Mountains and the main Andean range as well as fragments of Tertiary sandstones. The aggregate thickness of these deposits is about 400 feet. They are found in a group of three terraces which have been lifted above sea level to elevations ranging from a few feet to more than 1,200 feet.

The beds comprising these deposits are nearly horizontal and unconformably overlie the planed-off surface of the highly faulted Tertiary strata. These beds have a wide distribution south of the Mancora

valley and completely conceal the Tertiary strata in the greater part of this area.

Bosworth has named the three different terraces as follows: Mancora tablazo (highest terrace), Talara tablazo (middle terrace), and Lobitos tablazo (lowest terrace).

Recent.—Deposits of Recent age in this area may be divided as follows: alluvial plains and valley terraces, gravel fans, sand dunes, and saline deposits.

The alluvial plains and valley terraces are best developed in the valleys of the Chira and Tumbes rivers. The width of these deposits may range from a few hundred feet to several miles. They are composed of a rich soil and farming by irrigation is very extensive in areas where a water supply is available. The alluvial deposits are also developed, but to a smaller degree, in the other valleys of the district which have been mentioned previously.

The gravel fans are widely developed about the base of the Amotape and main Andes range. These may attain a thickness of a hundred feet or more and, as the name indicates, are composed chiefly of gravel. They extend from the base of the mountains for a mile or more out on the tablazos. Although not of special interest in themselves, they effectively conceal, in large areas, some interesting features of the geology, — the contact relations of the Tertiary sediments to the older strata in the mountains.

A narrow belt of sand dunes is found along nearly all parts of the coast line, which is marked by high sea cliffs. They are also very common for several miles inland south of the Parinas valley. Bosworth has described in some detail the occurrence, character, and mode of formation of these dunes, so that additional details will not be given here.

Saline deposits may be found in two parts of this area, the low land extending from Parinas Point southward toward Chira River, ranging from ½ to 1½ miles in width, and another low area several miles east of the Cerros de Illescas. The former area is so low that the sea water enters it during the high spring tides and leaves it covered. Upon evaporation of this water, a thin layer of salt is deposited. Where not gathered for commercial purposes, this salt is later covered with sand and dust carried by the wind. The following year another layer of salt is deposited and the process is repeated.

The same process takes place in the area east of the Cerros de Illescas except that the source of the water is Piura River.

Structural Geology

The major structural features of this district are the main Andean range, including the Amotape Mountains on the east and the Pacific fault which lies at the edge of the continental shelf on the west. The intervening area consists of strata which have been locally folded into small domes or anticlines and block-faulted.

The general trend of the main Andean range east of this area is north and south, and the trend of the Amotapes, a spur from the main range, is S. 50° W. The Amotape Mountains reach an elevation of 3,500 feet east of Negritos and probably 5,000 feet farther north. The main Andean range, of course, reaches a much higher elevation.

The Pacific fault has a general north-south trend. Its position is marked by a fairly uniform slope of 6 degrees, extending from the edge of the continental shelf at a depth of 600 feet to a depth of about 13,000 feet. The contoured slope is shown on the accompanying map (Fig. 1). These contours are based on data taken from the hydrographic charts of the United States Navy. The absence of specific data in some areas necessitated the projection of the contours for considerable distances in some places. However, it is believed that they represent approximately the contour of the ocean bottom in this district.

It will be observed that the continental shelf has its minimum width (3-4 miles) in the area from Cabo Blanco south to Punta Parinas and also along the coast west of the Cerros de Illescas. Between these points and also north and south of them, the shelf increases in width to as much as 30 miles.

In the region between the mountains and the coast line south of Chira River, there are two areas in which the Paleozoic rocks are exposed at the surface; these are the Cerros de Illescas and the Paita Mountains. These mountains probably formed islands throughout Tertiary time, as is shown by the fact that Tertiary rocks of Saman age were deposited on their lower slopes and the younger Tertiary strata exhibit a distinct shore phase.

The relation of the Tertiary strata to the older rocks is concealed by Pleistocene and Recent deposits around the greater part of these hills. Where exposed, it is found that the younger Tertiary strata have been faulted down against the older rocks and that they dip away from the mountains at a low angle. This relation may be observed along the east side of the Cerro de Illescas.

The greater part of the area south of Chira River which comprises the Sechura Desert is covered by Pliocene, Pleistocene, and Recent deposits. As a result, it is impossible to determine the true structural position of the older Tertiary strata. The Pliocene and Pleistocene (Tablazo) strata have been little disturbed and are found in a nearly horizontal position.

In the region between Chira River and the Mancora valley, several anticlinal folds and uplifted blocks have been formed. These structures, as well as the intervening areas, have been highly disturbed by normal faulting. These faults range in size from mere fractures to throws of 5,000 feet. The Tertiary strata in general dip away from the mountain mass. In places their relation to the older rocks is that of an unconformable overlap. This is especially true of the area east of the Amotape Mountains. Along the west side of these mountains the Tertiary strata are generally brought into contact with the older rocks by faulting.

Seven of the anticlines and uplifted blocks in this area are of sufficient importance to be worthy of mention. They are: the Saman anticline, the Tamarindo anticline, Punta Mirador uplift, Negritos-La Brea anticline, Jabonillal, Lobitos, and Restin-Cabo Blanco uplifts.

The Saman anticline is located in the Chira valley about 7 miles west of Sullana. The general axis of the structure trends S. 45° W. The dip of the strata ranges from 12 to 25 degrees. Several normal faults are found on this structure and in the adjoining area.

The Tamarindo anticline is a few miles northeast of the village of Tamarindo. The axis of this structure trends about S. 50° W. The dip of the strata ranges from 10 to 65 degrees. The high dips are due to the normal faults in the area. This structure is rather badly broken by faulting, especially on its southeast flank.

The Punta Mirador uplift is in the vicinity of Punta Mirador. It consists of an up-faulted block with the strata in general dipping northeast. Many beds are repeated as a result of normal strike faults. This uplifted area is separated from the Negritos-La Brea anticline by the large Pajarabobo syncline.

The Negritos-La Brea anticline might well be described as a general structural high area with several smaller anticlines developed on it. The two highest points on the structure are at Negritos and La Brea with several minor structural high areas developed on the saddle connecting these two.

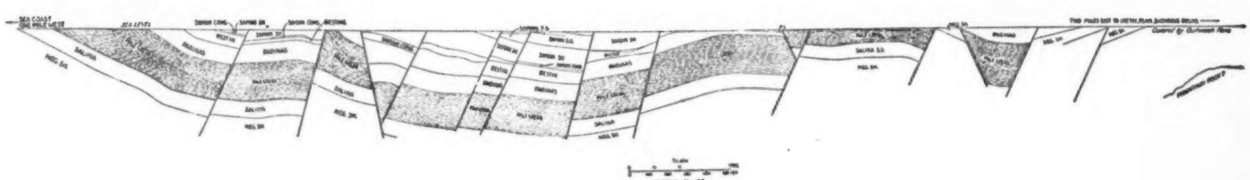


FIG. 2.—Cross section from the sea coast at Negritos eastward to the Amotape mountains.

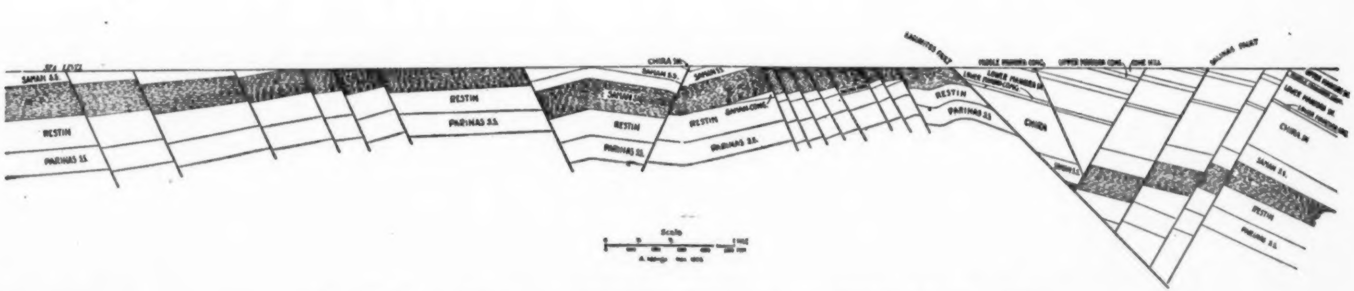


FIG. 3.—Cross section from near Talara south across Lomitos district of Negritos field.

The general high and its associated minor structures have been developed by a combination of two principal movements, namely, folding and normal faulting. One of these was at the close of middle Eocene time and the other in late Tertiary time. The movements which are registered in the lower and middle Oligocene strata in the coastal area undoubtedly affected this structure also.

The two accompanying cross-sections (Figs. 2 and 3) show the present position of the strata across this structure and along its axis. There are many normal faults which have a throw ranging from a few feet to 4,500 feet and the horizontal displacement may be as much as 2 or 3 miles. These faults may be dip, strike, or oblique faults and their great number results in many sudden and marked changes in the dip of the strata. These dips may range from a few degrees up to 60 or 70, the most common being 15 or 20 degrees. In some places the faults are marked by a zone several feet in width of badly crushed and contorted strata, but in other places the fault plane is very sharply defined and the strata are little disturbed on either side of it. The positions of the major faults in this area are shown on the accompanying geologic map. The three southernmost faults shown are down-thrown on the south side, but the northernmost shown at Negritos are down-thrown on the north side. The result of this faulting has been to leave a central mass of the older Eocene strata exposed at Negritos.

In the cross-section from Parinas Point to the Amotape Mountains it was possible to show the true dip of the strata in most places. In the section from Talara southward the actual dips in the northern part of the section are much steeper than shown, as the section is drawn obliquely to the dip of the beds. Sub-surface as well as surface data were used in compiling this section and they do not agree in all places, with the result that there may be some minor changes made in the northern part as more details are gathered regarding the variations in thickness of the formations due to the unconformities involved.

The effect of the folding and faulting which took place at the close of the middle Eocene is revealed in the sub-surface structure 3 or 4 miles east and northeast of Negritos. In this area the producing sand has been folded into a small anticline, the axis of which extends northeast and southwest. A part of the west side of this structure appears to have been faulted down. The prevailing dip of the surface beds above this structure is almost at right angles to the dip of the producing sand.

In the La Brea district the older strata are brought to the surface, in part by a normal westerly dip, but largely by faulting. The large

fault passing through Lagunitos may connect with the southernmost one shown in the La Brea district. The south side of this fault is downthrown so that upper Eocene strata come in contact with lower Eocene strata at La Brea.

On account of the highly faulted character of this structure, it will be impossible to describe it in detail in this short paper.

The Jabonillal uplift lies northeast of Negritos and is separated from the Negritos-La Brea anticline by a general synclinal area. This is a group of uplifted blocks with the younger strata down-faulted on nearly all sides of the central group. A large amount of intra-formational movement has taken place here, as shown by the highly contorted and crushed Saman shales. The oldest rocks exposed belong to the Restin formation.

At Lobitos and in the Restin-Cabo Blanco area, several up-faulted blocks are found. The strata dip at different angles and are much the same as in the Negritos district. The oldest rocks exposed in these districts belong to the Pale Greda formation.

In the area between the Mancora valley and Tumbes River, the Tertiary strata have a northwesterly dip. Normal faulting is very common, with strike faults as a conspicuous feature. These faults extend northeast and southwest, with the down-thrown side generally on the east. This results in a repetition of the beds and an apparent thickness much greater than the actual. A small amount of folding has taken place in this area but the faulting is a much more conspicuous feature.

At Zorritos an upfaulted block is found, from which there is a small amount of production. The strata in this block dip inland away from the coast.

Historical Geology

The main events in the geological history of the region since Cretaceous time may be briefly summarized.

During the Cretaceous, sedimentation was probably general over most of this region, including the southern portion of the Amotape Mountains and possibly the other mountain areas, such as the Cerros de Illescas and the Paita Mountains.

Toward the close of the Cretaceous, faulting began along the line of the Pananga fault. This fault cuts through the present Amotape Mountains in a direction about N. 58° W., crosses Quebrada Parinas near Quebrada Monte Grande, and probably comes to the coast a few

miles south of Restin. The block on the south was elevated, its Cretaceous rocks removed through erosion, exposing the underlying granite and Pennsylvanian slates, thus forming what is today the southern part of the Amotape Mountains.

The oldest Tertiary rocks of which we have any record are found in the Negritos region. From this general area as a locus, deposition spread north, south, and east, until the Tertiary shore-line was finally established along the present base of the Amotape Mountains and the main Andean range. The main area of deposition for the lower and middle Eocene seas lay north and west of the Chira valley, and in the extreme northern portion of the coastal area only the Restin or the uppermost part of the middle Eocene rocks were formed, and these mainly as coarse, coastal sandstones and conglomerates.

Deformation and faulting with subsequent erosion mark the close of mid-Eocene deposition. This was followed by a general subsidence and the upper Eocene or Saman sea transgressed widely over the entire coastal area both north and south. It carried Tertiary deposition far beyond its former limits and the upper Eocene sediments are therefore the most widespread of the Peruvian Tertiary formations and they may rest on any of the older rocks.

Alternately deep and shallow water conditions existed throughout Oligocene time. That deposition was, however, not continuous over the whole area is indicated by two unconformities of some importance at the base of the lower Oligocene and at the base of the middle Oligocene strata. For short periods of time, the coastal area was locally above sea-level and erosion was active, probably accompanied by some deformation.

The Miocene strata are limited to the northern and southern portions of the area. The extent to which they were originally deposited over the area and subsequently eroded is not known. In some places they overlie the Oligocene apparently conformably; in others, as in the case of the Tumbes valley, they overlap widely the older beds.

The Pliocene strata are found only in the southern part of the area and they were mainly deposited in comparatively shallow but quiet marine waters. As a rule, these rocks are but little disturbed, while the Miocene and older beds are generally badly broken by faulting. It is thus evident that the last great period of deformation occurred during the late Miocene or early Pliocene time.

During Plistocene time this area was near sea-level, or alternately above and below as shown by the terraces or tablazos. These geological

features and the Pleistocene history of the area have been thoroughly described by Bosworth, so that no further details will be given here.

Economic Geology

OCCURRENCE AND PRODUCTION OF PETROLEUM

The first indication that petroleum might exist in commercial quantities in the coastal area of Peru was found in the large seepages which occur there. It is known that these seepages were worked for their "pitch" in pre-colonial and colonial times.

Seepages of oil may be found in the Negritos, Lagunitos, La Brea, Jabonillal, Mogollon, Lobitos, Restin, La Breita, Zorritos, and Cerro de Illescas districts and on the Lobos Islands. The material of many of the formations gives off a petroliferous odor when freshly broken. A few gas seepages in the form of mud volcanoes are also found at La Brea and in the Quebrada Boca Pan.

Periodic attempts to work these deposits on a commercial scale for their petroleum products date back as far as 1862 in the Zorritos district, 1869 at La Brea, 1872 at Negritos, 1901 at Lobitos, and 1912 at Restin and Cabo Blanco. The work at Zorritos did not meet with a great deal of success until after 1883 and in the general Negritos-La Brea district not until 1889. These early failures were due largely to insufficient capital.

The yearly increase in the production from the coastal area since 1884 is shown in Table II.

The total production of the entire area to the end of 1926 was in excess of 73,000,000 barrels and the 1926 production was about 1,500,000 barrels greater than that of any preceding year. This production has come from four general districts: Negritos-La Brea, Lobitos, Restin-Cabo Blanco, and Zorritos. The production from the Jabonillal district is included in the Negritos-La Brea figures as the production from that district has not been large. The relative proportion of the production from these districts is approximately as follows: Negritos-La Brea, 76.2 per cent; Lobitos-Restin-Cabo Blanco, 20.3 per cent; and Zorritos, 3.5 per cent.

The Negritos-La Brea area (including Jabonillal and known as the La Brea-Parinas Estate) is operated by the International Petroleum Co. Ltd., the Lobitos-Restin-Cabo Blanco districts are operated by the Lobitos Oil Fields, Ltd., the Zorritos district is operated by Piaggio & Sons. The number of wells completed in the different districts at the end of 1926 was approximately as follows: Negritos-La Brea,

TABLE II

Peruvian Production

YEAR	LA BREA-PARINAS	LOBITOS-RESTIN	ZORRITOS	TOTAL PER YEAR	ACCUM. TOTAL
1872	....	....	....	....	....
1873	....	....	....	....	....
1874	....	....	....	....	....
1875	....	....	....	....	....
1876	....	....	....	....	....
1877	....	....	....	....	....
1878	....	....	....	....	....
1879	....	....	....	....	....
1880	....	....	....	....	....
1881	....	....	....	....	....
1882	....	....	....	....	....
1883	....	....	....	....	....
1884	....	....	5,501	5,501	....
1885	....	....	7,111	7,111	12,612
1886	....	....	7,834	7,834	20,446
1887	....	....	15,122	15,122	35,568
1888	....	....	15,257	15,257	50,825
1889	....	....	16,477	16,477	67,302
1890	8,132	....	21,270	29,402	96,704
1891	85,080	....	21,270	106,350	203,054
1892	127,620	....	28,360	155,980	359,034
1893	70,900	....	35,450	106,350	465,384
1894	53,175	....	35,450	88,625	554,009
1895	45,955	....	42,540	88,495	642,504
1896	43,688	....	44,936	88,624	731,128
1897	28,360	....	64,710	93,070	824,198
1898	76,783	....	64,916	141,699	965,897
1899	135,293	....	84,285	219,578	1,185,475
1900	203,860	....	97,352	301,212	1,486,687
1901	226,638	....	70,559	297,197	1,783,884
1902	195,116	....	56,032	251,148	2,035,032
1903	253,380	....	46,388	299,768	2,334,800
1904	276,602	....	46,836	323,438	2,658,238
1905	318,881	72,034	37,655	428,570	3,086,808
1906	327,493	133,558	39,093	500,144	3,586,952
1907	408,148	196,240	61,895	666,283	4,253,235
1908	564,689	324,170	71,429	960,288	5,213,523
1909	768,480	434,918	70,750	1,274,148	6,487,671
1910	802,232	405,414	107,000	1,314,646	7,802,317
1911	920,366	396,507	64,286	1,381,159	9,183,476
1912	1,116,305	594,875	78,095	1,789,275	10,972,751
1913	1,405,756	564,794	83,343	2,053,893	13,026,644
1914	1,337,726	509,899	88,136	1,935,761	14,962,405
1915	1,820,733	675,974	72,736	2,569,443	17,531,848
1916	1,882,249	662,788	73,852	2,618,889	20,150,737
1917	1,806,985	696,053	75,171	2,578,209	22,728,946
1918	1,820,814	647,618	76,190	2,544,622	25,273,568
1919	1,861,291	695,164	80,000	2,636,455	27,910,023
1920	1,993,349	739,624	93,698	2,826,671	30,736,694
1921	2,825,579	788,530	95,000	3,709,109	34,445,803
1922	4,386,938	839,108	73,539	5,299,585	39,745,388
1923	4,637,109	953,731	93,343	5,684,183	45,429,571
1924	6,477,662	1,335,806	90,000	7,903,468	53,333,039
1925	7,347,607	1,696,852	95,000(est.)	9,139,459	62,472,498
1926	8,532,125	2,000,000(est.)	100,000(est.)	10,632,125	73,104,623

* These figures have been gathered from several sources including the ***Bulletin of the Peruvian Bureau of Mines.*** Production given in barrels.

2,076 (approximately 1,300 producing at end of year); and Lobitos-Restin-Cabo Blanco-Zorritos, 350.

The depth at which production is secured in the Negritos-La Brea area ranges from 60 to 3,800 feet, with an average well depth of about 1,800 feet. The initial production of the wells may be as great as 4,000 barrels, but the average is about 300 barrels. The average life of the wells is between 10 and 11 years, although some of them have been producing for 26 years. The production per acre in some districts of this area is as high as 14,000 barrels and will be much higher than this before entirely exhausted.

Data giving the average depth of the wells in the Lobitos-Restin-Cabo Blanco district are not available, but it is believed that their average depth is slightly greater than in the Negritos-La Brea district and the initial production slightly less.

The depth of the wells in the Zorritos district ranges from 300 to 1,700 feet. The largest wells there do not produce much more than 250 barrels and the majority of them give an initial production of less than 100 barrels a day.

The oil from the coastal area has a "mixed" base and a low sulphur content. The average gravity of the oil from the Negritos-La Brea area is about 38° Bé. That produced from the other areas does not differ radically from this. These oils have a high gasoline content and yield an excellent quality of lubricating oil.

Several wells have been drilled to test territory outside of the present producing areas. These include about ten wells north, east, and south of the Zorritos district. Two of these were drilled as far south as the Quebrada Cardalitos. A shallow dry hole was drilled at La Breita. About four dry holes have been drilled in the Mogollon district, between the Jabonillal uplift and the base of the Amotape Mountains.

Two unsuccessful wells have been drilled on the Punta Mirador uplift and a third is now being drilled. Test wells are now being drilled on the Tamarindo and Saman anticlines in the Chira valley.

Shallow tests were made at Bayovar and near Raventazon about on the border of the Cerros de Illescas several years ago. Only small shows of oil were encountered. Additional tests are now being drilled a short distance east of the Cerros de Illescas.

New test wells are also being drilled at La Breita and Catalinas (in the Mancora valley). Preparations are also being made by a Lima company to drill a test well in the vicinity of the Quebrada Canoas.

The results which will be obtained in the new area now under development will go far toward indicating what may be expected regarding a greater expansion of the petroleum industry in the coastal area of Peru.

MOST IMPORTANT LITERATURE DEALING WITH THE GEOLOGY AND PALEONTOLOGY OF THE COASTAL AREA OF NORTHERN PERU

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NOTES ON THE TAYLOR AND NAVARRO FORMATIONS IN EAST-CENTRAL TEXAS[1]

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ABSTRACT

The relations of the Taylor and Navarro formations from Collin County to Travis County are briefly described and graphically shown in the accompanying map and diagram. The Pecan Gap tongue of the Annona chalk is shown to extend into, instead of above the top of, the Taylor marl as far south as Rockwall County. The Wolfe City sand member of the Taylor is recognized as far south as Hill County, and marl of uppermost Taylor age is shown to overlie the Pecan Gap and its equivalent, the Marlin chalk. Three new members of the Taylor are recognized, the Marlin chalk of Falls and Limestone counties, the Lott chalk of Falls and Bell counties, and the Durango sand of McLennan and Falls counties. The base of the Navarro is placed at the base of the zone of *Exogyra cancellata*, which is shown to correspond with the base of a sandy marl from Kaufman County to Milam County and to be a probable unconformity at least as far south as Falls County. The upper Navarro rests unconformably on the lower Navarro and cuts it from the section south of Milam County.

GENERAL STATEMENT

This paper records the results of a systematic, though brief, study of the subdivisions of the Taylor marl and the lower part of the Navarro formation, from Collin County southward to Milam County, Texas, by C. H. Dane in 1927, and there is included also the results of scattered observations on the stratigraphy and paleontology of the same formations carried on through several years by L. W. Stephenson. Especial attention was given to the Wolfe City sand member of the Taylor marl and to the Pecan Gap tongue of the Annona chalk, which extends into the Taylor, and to the relationships of these subdivisions to the Taylor. It is hoped that this report will give a general picture of the more obvious stratigraphic relations of the recognizable lithologic units, and that it will stimulate more detailed studies on the part of other interested geologists.

The Taylor and Navarro formations of the Upper Cretaceous (Gulf) series of Texas have been long known and approximately de-

[1]Manuscript received by the editor, October 10, 1927. Published by permission of the director of the U. S. Geological Survey.

fined[1], and are penetrated by wells in the important group of oil fields along the Corsicana-Mexia line of faulting; nevertheless, little precise information on their lithology and stratigraphic relations has been published, and students of the underground geology of the region have always experienced difficulty in differentiating the two formations in wells.

Stephenson,[2] in 1918, recognized in the beds of Taylor age two member units, the Wolfe City sand and overlying it the Pecan Gap chalk. Outcrops assigned to the Wolfe City sand were discovered as far west as the eastern part of Collin County, and the Pecan Gap chalk was believed to extend as far west and south as a point between Lavon and Nevada, also in Collin County. The present investigation has shown that these two members, with approximately the same physical character and relationship, can be traced as far south as Rockwall in Rockwall County, and that the Wolfe City sand extends still farther south.

RELATION OF THE PECAN GAP CHALK TO THE WOLFE CITY SAND

At the type locality of the Pecan Gap chalk half a mile east of Pecan Gap, Delta County, in a cut of the Gulf, Colorado & Santa Fe Railroad, the basal chalk is glauconitic, contains numerous phosphatic nodules, and rests upon the somewhat irregular surface of the top of the Wolfe City sand, which is here a soft, fine-grained argillaceous sand. This suggestion of unconformable relationship is not reinforced farther west, for at a locality in Rockwall County three-fourths of a mile north, then three-fourths of a mile west of Rockwall, along secondary roads, the lowest 3 feet of the Pecan Gap, which consists of hard blue chalk weathering white, changing to calcareous clay at the base, rests without irregularity on dark argillaceous sand of the Wolfe City. Furthermore, above this lowest pure chalk, the Pecan Gap contains interbedded layers of dark sand apparently identical with parts of the Wolfe City below. The thickness of the Pecan Gap here is not more than 40 feet. The Wolfe City elsewhere contains irregular beds and lenses of decidedly chalky character and the bases of some of these, well within the outcrop of the sand, are glauconitic, phosphatic, and irregular, closely

[1] J. A. Taff, "Reports on the Cretaceous area north of the Colorado River," *Third Ann. Rept. of the Geol. Survey of Texas*, 1892, p. 279. R. T. Hill, "Geography and Geology of the Black and Grand Prairies," *Twenty-first Ann. Rept. U. S. Geol. Survey*, Pt. 7, 1901, p. 335.

[2] L. W. Stephenson, "Contribution to the Geology of Northeastern Texas and Southeastern Oklahoma," *U. S. Geol. Survey Prof. Paper 120*, 1918, pp. 155-56.

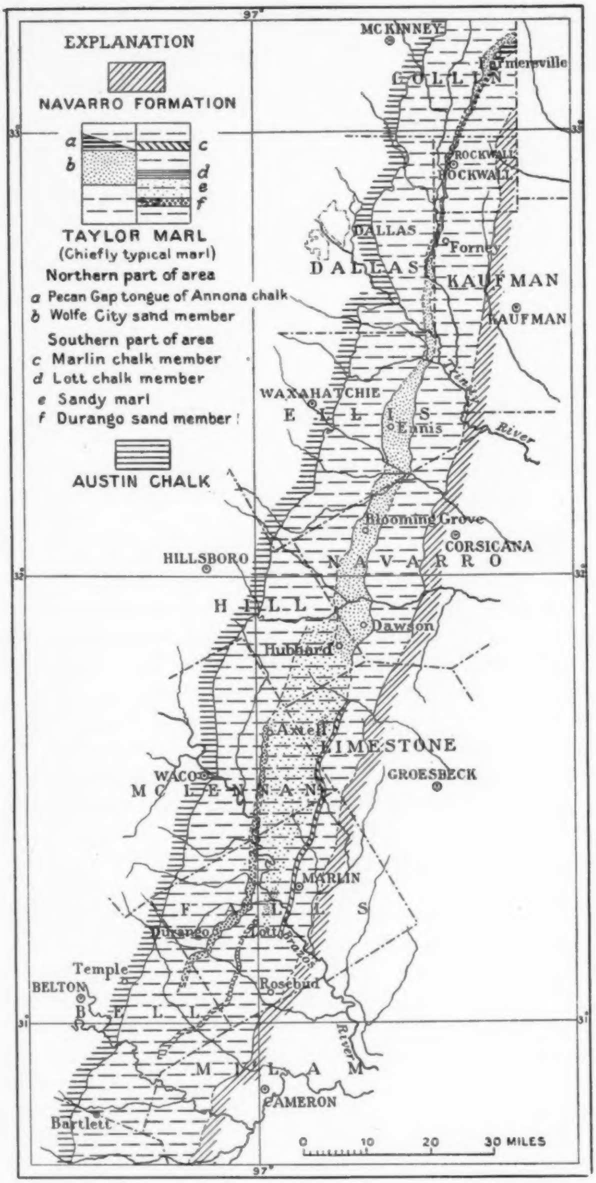


FIG. 1.—Geological map of the Taylor marl and its subdivisions from Collin County to Williamson County, Texas.

simulating the base of the Pecan Gap at the type locality, thus minimizing the authenticity of these phenomena as indicating a sedimentary break. The absence of any critical faunal change between the two members lends support to the view that no unconformity separates them.

South of Rockwall, in Rockwall and Kaufman counties, outcrops of the Pecan Gap chalk have not been discovered and the chalk probably grades laterally into chalky marl (Fig. 1). Exposures are poor through this stretch as the chalk belt should extend near the edge of the bottom of the East Fork of Trinity River. A specimen of *Echinocorys* cf. *E. texana* (Cragin), collected by W. A. George of Forney, Kaufman County, at a springhouse near his dwelling, 2 miles from Forney, probably came from marl above the Wolfe City sand, which corresponds in age to the Pecan Gap chalk. However, the direction of this locality from Forney is not stated on the label which accompanies the specimen. An outcrop in a drainage ditch on the north side of Mustang Creek, 3.1 miles N. 30° W. from Crandall, Kaufman County, represents the upper part of the southerly extension of the Pecan Gap chalk. This is a hard chalky marl, in part practically chalk.

RELATION OF WOLFE CITY SAND TO UNDERLYING BEDS OF TYPICAL TAYLOR MARL

The base of the Wolfe City was not seen in contact with beds of typical Taylor marl either at its type locality near Wolfe City or at any point farther east. The contact is exposed at several places in Collin County, from a point 1.7 miles west of Farmersville to a point 1.2 miles north of Lavon. Along this 8-mile stretch the basal Wolfe City is a glauconitic marly sand in which there are scattered casts of fossils and irregular nodules of phosphatic composition. The basal 3 inches in places contains irregular plates of phosphatic material as much as 5 inches square and an inch thick lying parallel to the bedding. In the vicinity of Farmersville the underlying beds of Taylor marl are pure, nearly black marl. Twenty or thirty feet below the base of the Wolfe City is a bed of calcareous siderite about a foot thick, containing pyrite patches and small phosphatic concretions. This ferruginous bed is traceable for several miles. The upper 50 feet of the lower Taylor is apparently variable in this area. This part of the Taylor is perceptibly sandy in the vicinity of Copeville and the upper 10 or 15 feet is slightly sandy in the vicinity of Rockwall, where there is apparently no break at the base of the Wolfe City, although the actual contact was not seen at the best outcrop visited, about 1.3 miles northwest

of Rockwall in the gullied cut of the proposed Dallas-Greenville interurban. The total thickness of the Wolfe City in this vicinity is estimated to be not more than 75 feet.

The Wolfe City sand outcrops in southwestern Rockwall County in the bank of Yankee Creek about 0.6 mile northwest of Heath along a secondary road and in road cuts above the creek exposure. About 20 feet altogether is exposed at this locality, partly massive fine-grained dark argillaceous sand and partly sandy marl with some layers of hard, slabby, lenticular calcareous sandstone from an inch to 5 inches thick. The total thickness of the member is unknown. South of this locality for many miles the probable extension of the Wolfe City sand belt of outcrop lies along the bottom land and terraces of the East Fork and West Fork of Trinity River and no outcrops of the sand are known along this stretch, although they may yet be discovered.

MARL ABOVE THE PECAN GAP CHALK

The Pecan Gap tongue of the Annona chalk from Collin County to the western part of Red River County, and the Annona chalk in the central and eastern parts of Red River County, are overlain by about 500 feet of marl which has heretofore been regarded in its entirety as forming the lower part of the Navarro formation.[1] The Marlbrook marl of Arkansas, which conformably overlies the Annona chalk of that state, has been interpreted as more closely related in age to the Taylor marl than it is to the Navarro formation, inasmuch as it carries to the very top a predominant proportion of a form of *Exogyra* closely related to *Exogyra ponderosa* Roemer, but with a smaller percentage of forms, showing a transitional variation toward *Exogyra cancellata* Stephenson and some fairly typical specimens of that species.[2] Although this faunal zone has not been recognized in northeast Texas, the present investigation has indicated that at least from Hunt County southward 300 feet or more of the marl overlying the Pecan Gap is more closely related to the Taylor than to the overlying Navarro, and is probably in part the equivalent of the Marlbrook marl of Arkansas. The original reference to the Navarro of the marl overlying the Annona chalk from Hunt County eastward has not been shown to be invalid, and the marl overlying the Annona chalk in Red River County seems to resemble

[1]L. W. Stephenson, "Notes on the Stratigraphy of the Upper Cretaceous Formations of Texas and Arkansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 1 (1927), p. 13.

[2]L. W. Stephenson, *op. cit.*, p. 11., C. H. Dane, "Upper Cretaceous Deposits of Southwestern Arkansas," *Bull. Ark. Geol. Survey* (in press).

typical Navarro marl in its lithology. Nevertheless, the occurrence of Taylor marl over the Pecan Gap tongue of the Annona chalk to the west makes it possible that some of the marl from Hunt County eastward is also of Taylor age. Unfortunately the marl above the Pecan Gap tongue is conspicuously and persistently devoid of diagnostic fossils other than those of microscopic size, and the evidence is largely, though not exclusively, indirect. All of our observations strongly indicate that there is no distinct break between the Pecan Gap chalk and this overlying marl from Collin County southward and that the chalk grades upward into chalky marl in which at places there are relatively thin beds of chalk for at least 100 feet above the top of the chalk. A single specimen of *Exogyra ponderosa* has been found in this zone at a locality about 2 miles north by east of Nevada along the road to Josephine. Upward the marl is less chalky and in places rather a calcareous clay with an abundance of fragments of *Inoceramus* and not uncommonly large poorly preserved compressed *Baculites*, with poor thin unidentified shell fragments. The maximum thickness of this marl is roughly estimated at 400 feet in Kaufman County.

From a point 2.5 miles southeast of Chisholm in southeast Rockwall County on the road to Terrell, along a line extending thence south by west through Kaufman County, this marl is overlain by a gray sandy calcareous clay or marl of unquestionable lower Navarro age. This clay carries a rather sparse fauna characterized by approximately equal proportions of *Exogyra cancellata* Stephenson and a varietal form of this species in which the surface of the shell tends to be smooth instead of cancellated. The typical *E. ponderosa* has not been found in this zone and *E. costata*, which elsewhere in the Coastal Plain is associated with *E. cancellata*, seems also to be rare or wanting.

At localities 4.25 and 4.65 miles from Kaufman on the road to Crandall, there are exposures of a 2-foot layer of strongly glauconitic marl with poorly preserved fossil prints and casts together with angular pieces and nodules of phosphatic material. This bed is overlain by sandy marl and below it the outcrops are chiefly non-sandy marl. Inasmuch as the bed lies only a short distance stratigraphically above large outcrops of the pure marl of the upper Taylor, it is not unlikely that it represents the base of the Navarro. The faunal assemblage of this sandy marl indicates an age considerably later than the upper part of the Marlbrook marl in Arkansas and is considered lower Navarro.

Cuts of the Texas and New Orleans Railroad less than a mile north of the two preceding localities have yielded fossils from approximately

the same zone, as follows: a cut 1½ miles east of Gastonia (4½ miles east of Crandall), *Ostrea panda* Morton and *Exogyra cancellata* Stephenson; a cut 1 mile east of Gastonia, *Ostrea panda* Morton, *O. tecticosta* Gabb, *Gryphaea* sp. (large), *Exogyra costata* Say, *Exogyra cancellata* Stephenson, and *Anomia argentaria* Morton.

This lithologic and faunal zone has been traced without apparent interruption southward to the latitude of Cameron and some further discussion of its character south of Trinity River will be given later. The persistence of the glauconitic and phosphatic zone at the base of the Navarro and its occurrence at a persistent lithologic break suggests that it marks an unconformity, but there is no conclusive evidence of this. North and east from southern Rockwall County the sandy constituent disappears and the differentiation of the Taylor and Navarro becomes almost purely a paleontologic problem, although the Navarro beds are typically less calcareous than the Taylor. *Exogyra cancellata* was found in calcareous clay or marl at several localities along the Greenville road within 3 miles northeast of Royce City; at 2.8 miles from that town this species was associated with a large smooth *Baculites* and with *Placenticeras?* (a fragment), and at 2.5 miles from the town the species occurred with *Anomia tellinoides* Morton (a diagnostic lower Navarro species), *Gyrodes* sp., a large *Baculites* and *Placenticeras?*. Approximately the same zone is represented by calcareous clay poorly exposed in a field south of the fair grounds at the southeastern edge of Greenville, Hunt County, where many typical specimens of *Exogyra cancellata* occur weathered out of the marly clay.

This zone carrying typical *Exogyra cancellata* is the lowest definitely known Navarro, and in view of the occurrence of *Exogyra ponderosa* only a little below the zone at one locality 2 miles north by east of Nevada in Collin County (see p. 46) it seems unlikely that any of the 300 to 400 feet of marl which intervenes between the Pecan Gap chalk and Wolfe City sand below, and the *Exogyra cancellata* zone above, will prove to be of Navarro age. The evidence for the Taylor age of the marl is, however, not as conclusive as might be desirable.

The *Exogyra cancellata* zone has been traced with certain interruptions throughout the Atlantic and Gulf Coastal Plain from New Jersey to Texas. At most places *Exogyra costata* Say is associated with *E. Cancellata*, though generally in lesser numbers, but in Texas *E. costata* seems to be rare in the zone.

THE WOLFE CITY SAND AND OVERLYING BEDS SOUTH OF TRINITY RIVER

South of the bottom and terrace sands of Trinity River, sandy beds in the upper part of the Taylor outcropping at the stratigraphic position of the Wolfe City sand and assigned to that member are of considerably greater thickness, probably at least 250 feet. This thickening is believed to be due to a southward increase in the sand content of the Taylor, the upper part of the sandy beds exposed in Ellis County being equivalent to the Wolfe City sand of Rockwall and Collin counties, and the lower part to the marl below the Wolfe City sand in those counties. Following the established and most serviceable practice, the name Wolfe City sand member of the Taylor is extended to include all the conspicuously sandy beds as far south as Hill County. In Ellis County it appears that there is a lower sand at the base of the unit and an upper sand at or near the top with an intervening zone composed chiefly of sandy shale with some beds of sand. About 25 feet of the lower sand is excellently exposed 0.3 mile north of Garrett, Ellis County, along the Dallas highway, both in a road cut and in a gully west of the road. Bedded fine-grained dark slightly argillaceous sand alternates with sandy clay, and near the top of the exposure is a 2-foot layer of thin-bedded hard gray slabby calcareous sandstone, brown on the weathered exposure. The sand makes a strong topographic ridge extending for several miles in a northeast by north direction from this place. There are similar outcrops 6.2 miles southwest of Ennis on the road to Byron, Ellis County, at the top of the east break of Waxahachie Creek, and 3.2 miles east of Bardwell on the road to Ennis in a similar topographic position at the top of the east break of Waxahachie Creek.

Outcrops of fine-grained argillaceous sand near the top of the belt are found in the bank of Four Mile Creek, 0.6 mile southwest of Crisp on the road to Ennis. An extraordinary type of sand outcrops near the top of the Wolfe City horizon from a mile to a mile and a half east of Bristol (7 to 8 miles east by north of Palmer) on the road to Slate Rock Ferry. This is an even-bedded, fine-grained clean quartz sand which weathers yellowish red. The individual beds are from ½ foot to 2 feet thick and there are hard calcareous lenticular sandstone beds with indistinct fossil impressions.

The Wolfe City sand in Ellis County is overlain by pure marl or calcareous clay lithologically identical with the marl overlying the

Pecan Gap chalk in Rockwall County, and occupying the same stratigraphic position. The chalk itself is apparently absent as such.

Southward in western Navarro County the thickness of the Wolfe City sand continues to increase to approximately 350 feet. The lower part of the unit is exposed from 1.3 to 3.3 miles along a secondary road to Long Cedar in a northwesterly direction from Blooming Grove, Navarro County. These outcrops resemble the basal part of the member in Ellis County and are characteristically well-bedded alternating sandy calcareous clay and soft marly sand, the individual beds varying between ¼ inch and 2 inches in thickness. There are a few lenticular layers of hard gray calcareous sandstone a few inches in thickness.

East of Blooming Grove on the road toward Barry, beds of different lithology are exposed. One and four-tenths miles east, gullied road ditches expose about 15 feet of soft nearly massive fine-grained yellow-weathering sand, and there are some hard irregular concretionary lenses of calcareous sandstone. On this road, 2.55 miles east of Blooming Grove, an exposure near the top of the Wolfe City reveals 25 feet of noticeably chalky sand interbedded in the soft sand. Throughout the lower part of the exposed sand, poorly preserved phosphatic casts of fossils are sparingly distributed.

It appears that the soft nearly clean sand which crops out 1.4 miles east of Blooming Grove is representative of a minor lithologic unit which is traceable through western Navarro County to the vicinity of Dawson. Outcrops of similar lithology are found in the bank of a small creek, a little less than half a mile southwest of Dawson on the road toward Hubbard, and more conspicuously from 2.7 to 3.1 miles north of Dawson on the road to the Spring Hill settlement. These road cuts expose an estimated total of 60 feet of fine-grained yellow-weathering nearly clean sand with harder irregular calcareous lenses.

In Navarro County, as in Ellis County, no chalk was observed at the horizon of the Pecan Gap chalk. Overlying the Wolfe City sand is a pure marl in places chalky in the lower part and apparently devoid of diagnostic fossils. It is probably somewhat more than 400 feet in maximum thickness. The marl is succeeded above by the sandy marl of the lower Navarro with its lithologic character and fauna closely resembling that north of Trinity River in Kaufman County, typically a palpably sandy marl with a few ellipsoidal concretions of dense gray carbonate which range from a few inches to several feet in diameter. Two outcrops of glauconitic marl have been found in Navarro County near the base of this lithologic and faunal unit, but the actual basal

contact has not been discovered. At 2.1 miles east of Drane on the road to Corbet near the west edge of Briar Creek bottom is an outcrop of glauconitic sandy marl with typical lower Navarro overlying it. The glauconitic bed is stratigraphically the lowest Navarro outcrop seen in this vicinity. A still more significant outcrop is 9.9 miles east of Dawson on the road to Corsicana. At this place the road ditch exposes 2 or 3 feet of sandy glauconitic marl with many fossil shell prints. Overlying it is massive to bedded sandy marl with hard spheroidal limestone concretions weathering white. Less than one-fifth mile west and stratigraphically below this outcrop is a good exposure of the pure marl of the upper Taylor lithology.

The base of the Wolfe City sand in Hill County has been arbitrarily set at the stratigraphic horizon of a locality 0.9 mile west-northwest of the center of Hubbard on the road to Hillsboro. At this locality bedded marly sand crops out with some beds of sandy marl. Above this horizon the beds are predominantly sandy, below it only moderately so. This arbitrary procedure has been adopted of necessity, as the phenomenon of lower and lower beds in the Taylor becoming sandy by transition southward along the belt of outcrop has occurred so extensively in southern Hill County that less than the lowest 400 feet of the Taylor can be correctly described without qualification as marl.

From Hubbard northwest toward Hillsboro for more than 5 miles the outcrops are thin-bedded sandy marl, marl, and sand. The sandy marl and pure marl beds range from ½ inch to 1 inch in thickness and are regularly and repeatedly separated by sheets of clean soft sand about 1/32 of an inch thick. There are a few thin hard lenses of calcareous sandstone. The pure marl of the lower Taylor outcrops only 5.9 miles northwest of Hubbard on the road toward Hillsboro. The sandy calcareous clay below the Wolfe City sand of Hill County becomes increasingly sandy southward through McLennan and Falls Counties. On the contrary the 350-foot section included in the Wolfe City sand in southern Hill and southwestern Navarro counties becomes decreasingly sandy southward through Limestone and eastern McLennan counties. Characteristically it is a bedded sandy marl with regular even beds of either pure or slightly sandy marl ranging from ½ to 1 inch thick, with intervening thinner sheets and vermicular pockets of soft clean sand. A few lenses of hard calcareous sandstone may be as much as 4 inches thick. There are, however, some beds of sand, one or more of which may be persistent. An outcrop 8.1 miles south-southwest along the road from Prairie Hill in Limestone County toward Mart exposes

6 feet of calcareous sand, the upper 2 feet of which is sufficiently hard to make a ledge. Above this crops out bedded very sandy marl. Altogether there is probably a thickness of about 550 feet[1] of this sandy marl, the upper part of which is equivalent to the Wolfe City sand of Hill and Navarro counties, and the lower part of which is equivalent to sandy marl in Hill County. It is suggested that the name Wolfe City sand be arbitrarily dropped south of Hill and Navarro counties, although it is recognized that sandy beds in the upper part of the Taylor extend at least as far south as central Falls County. A notable exposure of sandy beds occurs on the road to Cedar Springs at the crossing of Deer Creek 6 miles from Marlin. The creek bank at this place exposes 30 feet of bedded gray clay, sandy marl, fine soft sand and hard calcareous sandstone in alternating beds which show remarkable parallelism, some beds extending hundreds of feet without perceptible divergence. Beds of sand and sandy marl occur also along the Marlin road 2 to 3 miles northeast of Lott.

DURANGO SAND MEMBER OF TAYLOR MARL

The base of the sandy beds within the Taylor is, however, a definite, sharply marked contact most of the way from southern Hill County to the Bell County line, about 350 to 400 feet above the top of the Austin chalk, and above this contact in McLennan and Falls counties is a sand of recognizable continuity and importance, to which the name Durango sand member is here given. In McLennan County the sand is best exposed at a locality about 2 miles south of Axtell in the bank of Williams Creek at a bridge crossing on a secondary road from Axtell to the Waco-Prairie Hill road. At this place about 5 feet of hard sand and calcereous sandstone with plentiful comminuted shell fragments make a ledge several hundred feet in length along the north bank of the creek. The basal contact is irregular and sharp and beneath it soft black marl crops out. This contains scattered yellow-weathering ellipsoidal concretionary lumps of limestone ranging from 1 to 3 inches in diameter. The beds south of this outcrop are broken by a small fault and flexure with the downthrow toward the north. The contact is again exposed a little more than a mile southeast of the Williams Creek outcrop along the road and also at the faulted exposure in a small branch about half a mile south of the Williams Creek outcrop. Above the hard basal sandstone there are indications that there is at least 5 feet of soft marly sand.

[1]This figure is based on the interpretation of logs of wells drilled in northwestern Limestone County.

The bottom lands and terrace sands of the Brazos conceal outcrops of the bed for some miles to the south.

In Falls County this sand is evidently much thicker. On the road to Lott, 1.2 miles south of Chilton, just south of Deer Creek bottom, where a secondary road turns southwest, the road cuts expose the following section:

DURANGO SAND MEMBER 1.2 MILES SOUTH OF CHILTON

	FEET
Soft calcareous sand with some layers of hard gray calcareous sandstone and a few interbedded layers of irregular gray clay	50
Thin-bedded calcareous sandstone and softer chalky cross-bedded sand; in the lower half thin beds carry many comminuted shells, larger shell fragments, subangular grit-sized grains of black phosphatic material, and a few fish teeth	15

The lower part of the section is broken by slight faulting or slump. The topography suggests that the hard sandstone ledge is probably the base of this sandy member and the soil change shows that the bed rock below it is probably soft non-sandy marl.

This thick sand extends southwestward from this locality through Durango to the small settlement of Theo on the Bell-Falls county line. There are many excellent exposures on the road from Durango to Chilton and also 0.6 mile northwest of Durango, 0.8 mile east of Durango, and 3.8 miles from Westphalia on a secondary road to Bell-Falls at a locality about a mile south of Jena. In the vicinity of Durango the sand is apparently transitional into the marl below. Southwestward into Bell County the sand merges into sandy marl and thence into marl with a scarcely perceptible sand content. Probably no significant lapse of time is indicated by the sharpness of contact and irregularity here and there at the base of the Durango sand member.

LOTT CHALK MEMBER OF TAYLOR MARL

In southwestern Falls County the southward decrease in the sand constituent of the Taylor below the horizon of the chalk described below as the Marlin chalk member has progressed to such an extent that none of it shows an appreciable percentage of sand. In addition there appears at a horizon several hundred feet below the position of the Marlin chalk, a chalky marl bed which in places can properly be called

a chalk. The northernmost outcrops of this bed are in the vicinity of Lott, from which place it is proposed to call this bed the Lott chalk member of the Taylor marl. It extends southwestward through Falls County and good outcrops occur from 1 to 3 miles west-northwest of Rogers in Bell County on the road to Little River. The Lott chalk is probably not more than 40 feet thick at any place along its outcrop. The bed is rather plentifully fossiliferous with *Gryphaea vesicularis* Lamarck (variety), *Exogyra ponderosa* Roemer, *Ostrea plumosa* Morton, *Inoceramus* sp., and *Hamulus* sp., and there are in places thin beds of coquina, a few feet in length, composed chiefly of fragments of the shells of *Ostrea* and *Inoceramus*. Fragments of *Echinocorys* aff. *E. texana* (Cragin) have also been found in it. The member has not yet been traced south of the vicinity of Rogers.

MARLIN CHALK MEMBER OF TAYLOR MARL

In Limestone County chalk at the approximate position of the Pecan Gap chalk reappears in the section and has been traced southward through the eastern corner of McLennan County and through Falls County to a point a few miles south of Brazos River. This is a pure white chalk, in part hard and tough, and in part soft and marly. The granular texture and admixture of sand which is found in places in the Pecan Gap chalk has not been observed in the Marlin chalk. The essential lithology is similar, however, and the fauna is in part comparable.

The chalk carries a characteristic assemblage of fossils several species of which seem to be restricted to this zone in Texas. The assemblage includes worm tubes of the species *Hamulus onyx* Morton, and *H. squamosus* Gabb, fragments of the echinoid *Echinocorys* aff. *E. texana* (Cragin), unidentified echinoid spines, the brachiopod genus *Terebratulina?*, *Ostrea plumosa* Morton, *Gryphaeostrea vomer* (Morton), *Gryphaea* (smooth-convex species), *Pecten* sp., and *Plicatula* (a small smooth species). Of the forms enumerated *Echinocorys*, *Ostrea plumosa*, and the smooth-convex species of *Gryphaea* occur in the Pecan Gap chalk and in the upper part of the Annona chalk. Although the Marlin chalk is believed to be approximately of the same age as the Pecan Gap chalk, the paleontologic evidence for this correlation is not conclusive, for both the *Echinocorys* and the *Gryphaea* are known to occur in beds that are stratigraphically lower than the Pecan Gap, and the oyster is a long-ranging species. A *Terebratulina?*, two species of *Hamulus*, a smooth-convex *Gryphaea*, and a *Plicatula* similar to those found in the

Marlin chalk occur in the cement rock facies of the Selma chalk in the cliffs on Tombigbee River, at and near Demopolis, Alabama, and the Marlin chalk is therefore believed to be about the same age as that part of the Selma.

The Marlin chalk is typically exposed 0.4 and 0.9 mile south of the courthouse at Marlin, Falls County, along the edge of the bottom lands of Brazos River, in a small scarp facing west. At the latter locality 200 yards south of the plant of the Branson Brick Company, this small scarp exposes about 4 feet of soft argillaceous creamy chalk merging into 5 feet of pure chalk below; the marly chalk above carries the characteristic fauna already enumerated.

The Marlin chalk can be traced north by east from Marlin by means of several small exposures to a large exposure 3.2 miles south by east of Mart in McLennan County, on a secondary road toward Otto at the crossing of Big Creek. The creek bank for several hundred yards exposes about 15 feet of bedded marly and pure chalk which carries the smooth-convex species of *Gryphaea*, *Echinocorys* aff. *E. texana* (Cragin) and a few other fossils. A similar but smaller outcrop is on the bank of Big Creek at the crossing of the Mart to Riesel road about half a mile southwest of Mart. The total thickness is somewhat less than 50 feet in the vicinity of Mart and probably gradually thins northeastward to a small outcrop 2.3 miles west of Prairie Hill, Limestone County, on the road to Waco, where the road ditch exposes 3 feet of white marly chalk with a few hard concretionary lenses of sandy limestone. The point farthest northeast at which the chalk was observed is 3.2 miles north by west of Prairie Hill, about 2 miles southwest of Delia, on a secondary road toward Hubbard, where the road cut exposes a few feet of soft white chalk.

Underlying the chalk west and northwest of Prairie Hill are sandy shale and calcareous sand undoubtedly equivalent to the upper part of the Wolfe City sand as exposed in southwestern Navarro County. Toward the southwest the sandy constituent diminishes and in the vicinity of Mart and Marlin the beds immediately below the chalk are pure marl without perceptible sand content.

The chalk at Marlin extends southwestward across Brazos River, and its outcrop makes the so-called Falls of Brazos River, 4.5 miles from Marlin. The outcrop was concealed by high water at the time of Dane's visit, but Frank Bryan of Waco is authority for the statement that the bed of hard white chalk strikes N. 15° E. entirely across the river. Two outcrops of the chalk were examined southwest of the Brazos,

both on the Marlin-Cedar Springs road, one 5.3 and the other 5.8 miles south of the crossing of Deer Creek, both approximately in line with the southwestward extension of the outcrop at the Falls of the Brazos. The faunal assemblage at these localities corresponds to that at the plant of the Branson Brick Company near Marlin.

MARL OF TAYLOR AGE ABOVE THE MARLIN CHALK

Above the Marlin chalk in Limestone and Falls counties, pure marl crops out in many places, chalky toward the base, but gradually less calcareous upward and without diagnostic fossils that have as yet been discovered. This marl duplicates in its lithologic character the marl assigned to the uppermost Taylor farther north and occupies the same stratigraphic position. It unquestionably thins toward the south and is probably not much more than 250 feet thick in Falls County.

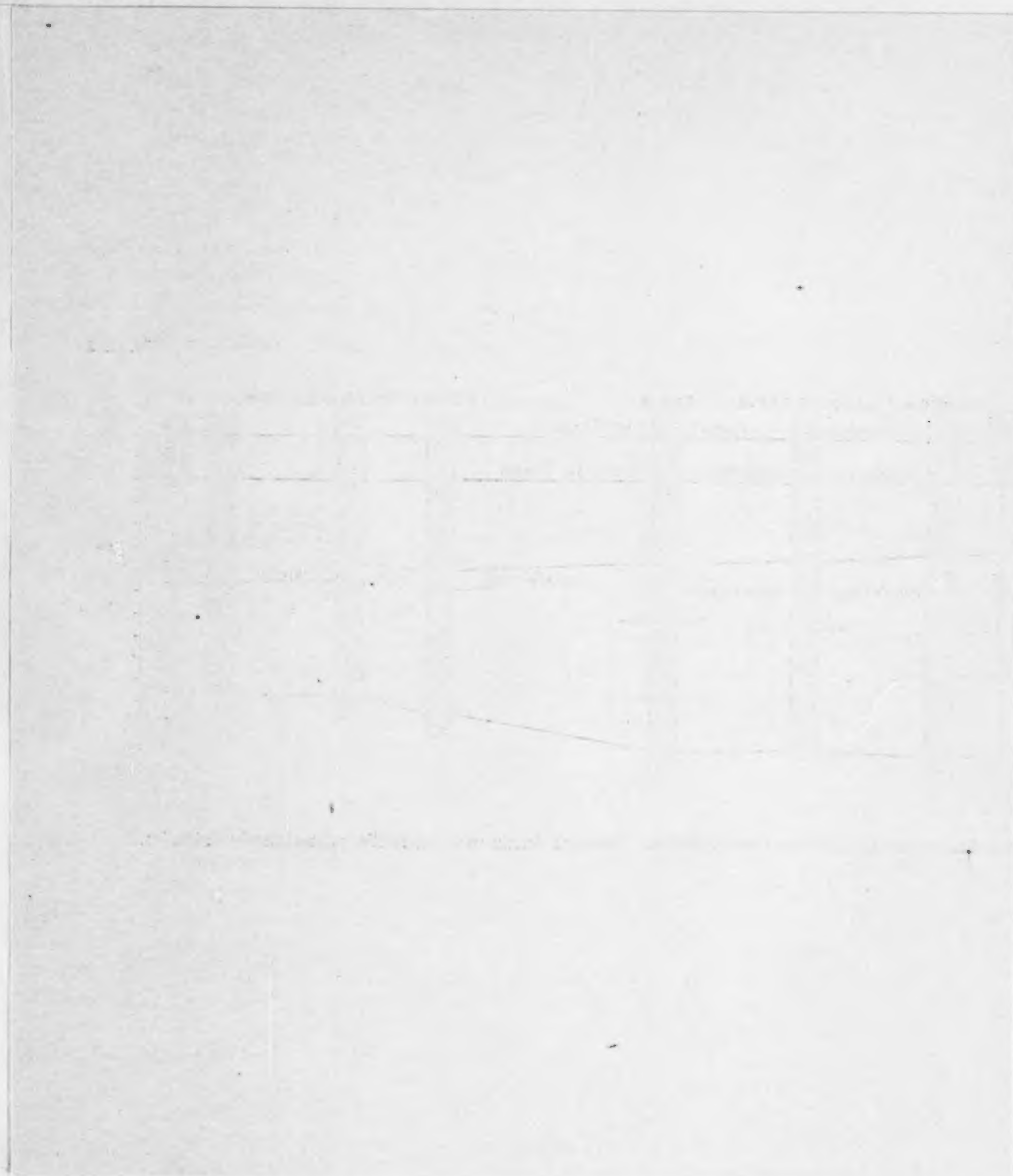
Traced southwestward through Falls County this upper part of the Taylor begins to exhibit slight variability after having remained extremely uniform from Collin County southward. Of particular importance is the increased fossil content in some outcrops and the presence here and there of specimens of typical *Exogyra ponderosa*, confirming the belief that this marl both in this locality and farther north is of Taylor age. For the most part the marl remains pure but some outcrops have concretionary limestone lenses several feet in length, some of which are mostly crystalline calcite. In a few places a slightly sandy constituent is noticed and an outcrop 0.6 mile north of Burlington, Milam County, on the road to Rosebud, is a sandy marl with sandy concretionary lenses, which is lithologically similar to the lower part of the Navarro but carries only *Exogyra ponderosa*. These variations are, however, minor ones and the great mass of the material remains a uniform pure marl.

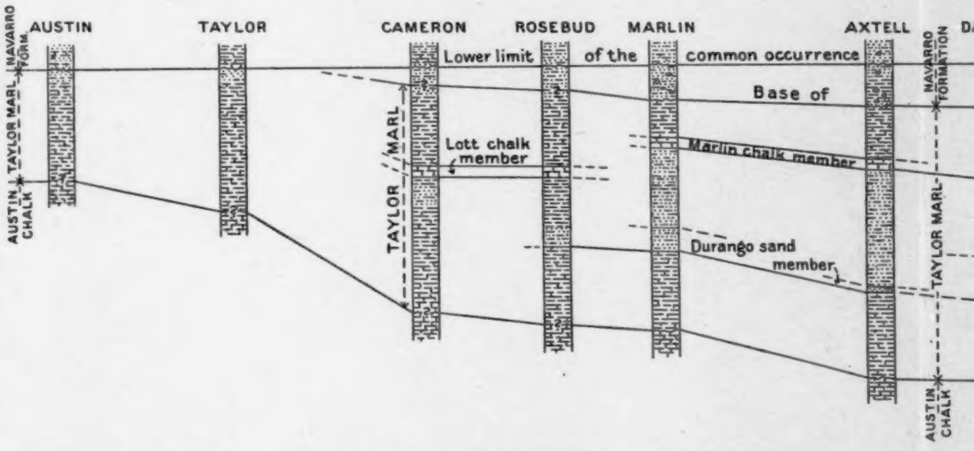
BASAL BEDS OF THE NAVARRO FORMATION

Overlying the uppermost Taylor marl from Navarro County southward at least to the latitude of Cameron in Milam County is sandy marl of lower Navarro age, which is for the most part lithologically and faunally like the lower Navarro of Kaufman and Navarro County already described. In the northern part of Limestone County, however, the position of the contact is obscure, for in this one short stretch the basal portion of the Navarro is much less sandy than to the north and south, and the fossil content simultaneously decreases. The lower Navarro can generally be recognized by its less calcareous nature and the presence of large dense gray limestone concretions. Southwest-

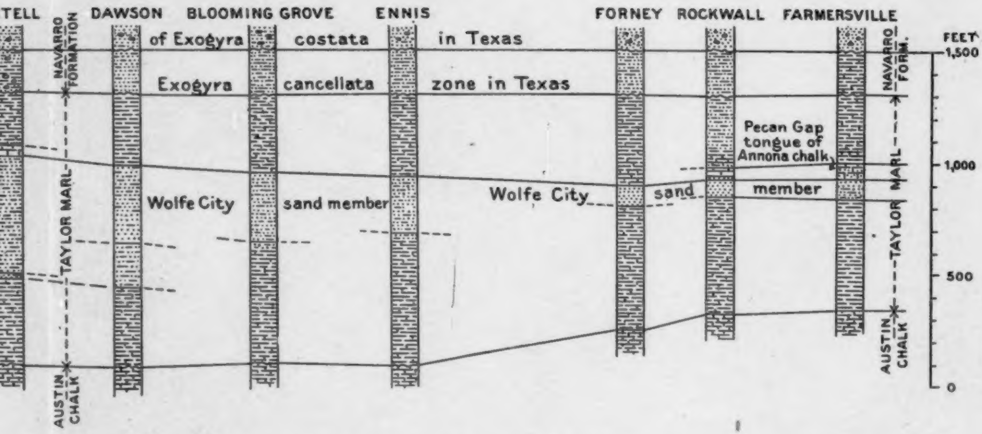
ward from a point 4.2 miles east of Prairie Hill in Limestone County, the sandy constituent of the lower Navarro is again conspicuous. Worthy of notice is a small outcrop 5 miles (by the road) generally east-southeast from Mart on the road to Groesbeck, where a bed of glauconitic sandy marl is again encountered approximately at the position of the base of the Navarro. An outcrop of sandy marl with large concretionary limestone lenses weathering white, located 6.1 miles northeast of McClanahan, Falls County, on a secondary road past Eureka Schoolhouse, and just west of the bottom of Big Creek, contains *Exogyra cancellata* and extends the lithologic and faunal zone into Falls County. An outcrop 1.7 miles south of Burlington, Milam County, on the road to Cameron, exposes the same sandy marl with the typical *Exogyra* assemblage of this lower Navarro, consisting of approximately equal proportions of typical *Exogyra cancellata* and a smoother varietal form of the same species. As previously noted, 0.6 mile north of Burlington on the road to Rosebud, there is a lithologically identical exposure with only *Exogyra ponderosa*. There is thus a suggestion that the break believed to exist at the base of the lower Navarro farther north has here disappeared and that the relations are transitional, a suggestion which is reinforced by the relations farther south. The same co-mingling of noded and nearly smooth *Exogyra cancellata* is found in an outcrop exposing about 20 feet of sandy marl, 7.4 miles northwest of Cameron on the road toward Buckholts in Milam County.

The thickness of the lower Navarro is only approximately known but is probably about 200 feet in Kaufman and Navarro counties. It gradually thins to the south and is probably not more than 50 feet thick in Milam County. This gradual thinning to the south suggests an unconformity within the Navarro at the base of the beds containing *Exogyra costata* (See Pl. 2). and the disappearance of the zone of *Exogyra cancellata* south of Falls County tends strongly to confirm this suggestion. There is little physical evidence for this unconformity, but a single outcrop located 7 miles northwest of Cameron on the road toward Buckholts adds considerably to the paleontologic evidence. At this place gray sandy marl of typical lower Navarro lithology, such as outcrops only 0.4 mile farther northwest with a typical fauna, is overlain on a somewhat irregular contact by a 2-foot bed of richly glauconitic green marly sand which carries typical *Exogyra costata* in association with strongly noded *Exogyra cancellata*, identical with the forms found in the Saratoga chalk of Arkansas. Above this basal glauconitic bed crops out 5 feet of pure white chalky marl. The outcrop is broken by





Generalized section showing the stratigraphic relations of the Taylor marl and the Navarro formation from C



...ation from Collin County to Travis County, Texas. Distance Austin to Farmersville, approximately 216 miles.

Elgin road, north of the house on the Mrs. T. Burke property, 3.3 miles east by north of Manor. At the two last described localities, beds which carry an upper Navarro fauna crop out within less than a hundred yards to the east, and this close geographic association, and the occurrence of many fragments of slickensided vein calcite in the soil indicate that in this part of Travis County the upper part of the Navarro formation has been faulted down against the uppermost beds of the Taylor marl along a fault which trends about N. 27° E. The magnitude of the displacement along this fault has not been determined.

LOGGING ROTARY WELLS FROM DRILL CUTTINGS[1]

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ABSTRACT

Experiments made by the geological departments of the Marland Oil Company of Oklahoma and the Gypsy Oil Company, respectively, have shown that a satisfactory log can be made from a continuous set of rotary cuttings.

To be satisfactory for this work the samples must be collected by a device capable of making a continuous, automatic separation of a representative sample of the cuttings. Most sampling devices employ one or the other of two basic principles—straining or settling. The settling devices have proved the more satisfactory. Where a wooden flume carries the returns direct to the settling pit, the settling of cuttings can usually be accomplished by installing a weir or dam in the flume itself. This checks the velocity of the mud stream and causes the cuttings to be deposited above the weir. Where the use of the flume weir is impracticable, the samples can be obtained by diverting a portion of the returns to a specially constructed collecting box in which the separation is also accomplished by the use of a weir to reduce the rate of flow.

Especial care is necessary in the washing of rotary cuttings. Since each individual fragment of sand, shale, or limestone, as it comes from the well, is coated with a thin film of rotary mud, it is absolutely impossible to distinguish one type of rock from another unless this coating of mud is removed by a thorough washing of the sample.

Reasonably accurate depth measurements are essential if the log is to be of any value for structure mapping. There are two possible sources of errors in determining the depth which is represented by the sample; those due to inaccuracies in determining the depth at which the drill is working and those due to the lag in the return of the cuttings.

The errors in the determination of the drilling depth are by far the more serious. The only satisfactory method of obtaining depth measurements is to measure, with a steel tape, the length of each joint of drill pipe as it is first run into the hole. Since the errors due to lag are only excessive where the rate of progress is great, they can usually be disregarded.

The preliminary description of rotary cuttings is simply a record of the approximate percentages of sand, lime, shale, gypsum, and other constituents, with appropriate descriptions as to color, texture and fossil content, of the material present in the sample. It is the abrupt changes which appear in such a sequence of samples that are significant rather than the gross material in the individual sample. The contacts between the different formations can be located with reasonable accuracy by noting the depths at which these abrupt changes take place. The final log is simply a record of these contacts and is identical in form with the ordinary log made by the driller.

In addition to the data contained in the log, fragments of the sands may be tested for possible oil content by using some of the ordinary solvents and noting the

[1]Published by permission of the Marland Oil Company of Oklahoma and the Gypsy Oil Company. Manuscript received by the editor, October 10, 1927.

[2]Marland Oil Company.

[3]Gypsy Oil Company.

discoloration, or subjecting a small charge of fragments of the sand to a simple distillation test.

INTRODUCTION

It is only within the last few years that logs of wells drilled with rotary tools have become a really serious problem to the Oklahoma geologist. In fact, prior to the development of the Tonkawa field the rotary was practically unknown in the northern part of the state, and even in southern Oklahoma, which was regarded as "rotary country," much of the wild-catting was done with cable tools.

While the unsatisfactory nature of the ordinary rotary driller's log was generally recognized, as long as cable-tool logs were available for correlations and control for structure mapping, the tendency was to accept that as one of the inevitable drawbacks attached to the rotary method of drilling.

There were, of course, some attempts to improve the rotary logs. A paper,[1] "Logging Wells Drilled by the Rotary Method," by Edgar Kraus, stressed the possibilities of improvement in a more intensive application of the methods then in use, that is, a closer study of the action of the drill and the pumps, supplemented by an occasional examination of samples from the return line.

The net results of such efforts seem to have been negligible, so far as any general effect on the logs was concerned.

But when it became apparent that the rotary would probably largely supersede the cable-tool system in Oklahoma, for the development of fields with several sands and high gas pressures, and also for wild-catting where the contract depth was to be much in excess of 4,000 feet, it was obvious that some system of obtaining accurate logs must be devised, or an enormous amount of valuable geological information would be lost.

Accordingly, a series of experiments in logging rotary wells from complete sets of rotary drill cuttings was undertaken by members of the geological staffs of the Marland Oil Company of Oklahoma and the Gypsy Oil Company, respectively. These experiments soon showed conclusively that a satisfactory log of the formations penetrated could be obtained in this manner. Further work also went far toward banishing the other big objection to the use of the rotary on wild-cat wells, namely, the possibility of passing up an oil-bearing sand without recognizing it as such, since it was found that the presence of oil in a sand

[1]*Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 5 (September-October, 1924).

could invariably be detected in the cuttings by a simple distillation test.

The methods evolved by these experiments have already been adopted by many of the major operating companies in the state, but their use is not yet universal and their usefulness is dependent both on the method of sampling and the interpretation of these samples in making up a finished log.

For that reason the following discussion of the methods of sampling, sample washing, depth measurements, and the examination and interpretation of the cuttings, has been prepared in the hope that it will lead to a more widespread use of drill cuttings as the basis for rotary logs, and a consequent economic gain to the oil industry as a whole.

SAMPLING

The value of the results obtained from the examination of rotary cuttings depends largely upon the quality of the sample collected. A satisfactory sample may be defined as one which is truly representative of all the cuttings issuing from the return line during the drilling interval which the sample is supposed to represent. Such a sample can not be obtained by catching a bucket full of cuttings at some particular moment, but must be obtained by some device which operates throughout the entire drilling interval and separates out a small portion of the cuttings passing it in each successive increment of time. A good sampling device, therefore, must be capable of making a continuous, automatic separation of a representative sample of sufficient volume to permit a complete examination. Simplicity, accessibility, and ease of handling are also important factors influencing the results obtained.

Practically all devices used for extracting cuttings from rotary mud employ one or the other, or a combination, of two basic principles, straining or settling.

The straining type accomplishes the separation by means of some form of screen which will retain the cuttings but allow the mud to pass through. Screens of innumerable shapes and sizes have been used for this purpose, but they all possess certain disadvantages. They are mechanically weak, easily distorted and broken, heavy to handle and hard to clean. An added disadvantage with the ordinary screen is that it collects only the coarser cuttings, and allows much of the finer material to escape. It is in this finer material that the greater number of fossils are found.

Settling devices accomplish the separation of cuttings from the mud-laden fluid by reducing the velocity of its flow sufficiently to

cause a part of the cuttings to be deposited in the bottom of the sampling device. They have proved the most satisfactory of any yet devised, have the fewest drawbacks and offer the greatest flexibility of installation and operation.

A simple application of the settling method can be made on wells where a wooden sluice box is used to carry the return stream of mud-fluid from the rig to the settling pit. Under such conditions the necessary reduction in velocity of the mud-fluid can usually be accomplished in the sluice box itself, by installing a removable dam or weir. An inch board extending across the full width of the sluice box and with its height depending on the height of the sluice walls and the velocity of the stream, held in place by upright cleats nailed to opposite sluice walls, serves the purpose of a dam and is easily adjusted. A wooden handle facilitates its removal and replacement.

The method of operation is as follows: the weir is put in place and allowed to remain while the desired footage, usually 10 feet, is being drilled; the cuttings which have collected back of the weir are then removed with a scoop shovel, and placed in a bucket for washing; then the weir is removed and the shovel run through the sluice again to help the mud-fluid remove any remainder of accumulated cuttings; the weir is then replaced and this cycle repeated.

Some rigs use a pipe instead of a wooden sluice box to carry the returns, in which case the method just described is obviously inapplicable, and in some places where the sluice box is used its gradient is such as to give the mud-fluid too great a velocity to permit satisfactory sampling by this method. In such cases the same principle of operation may be applied by diverting a part of the stream of mud-fluid from the sluice box or return line to a specially constructed collecting box.

The construction of such a collecting box is illustrated in Figure 1. It is merely a rectangular box of the following approximate dimensions: 8 inches wide, 8 inches high, and 5 feet long. One end is permanently closed and the other is fitted with a removable weir about half the height of the box. This weir rests loosely against cleats nailed to opposite walls of the box and should be only tight enough to avoid excessive leakage around the ends. If desired the discharge may be through an opening in the side of the box below the weir, instead of at the end.

The method of operation is identical with that used where samples are collected in the regular sluice box. The diverted slush is introduced into the collecting box at the closed end, flows the length of the box, and is discharged over the weir at the other end, the cuttings settling out in

the bottom of the box. The volume of the sample obtained is governed by the height of the weir and the amount of slush entering the box. At appropriate intervals the accumulated cuttings are removed with the

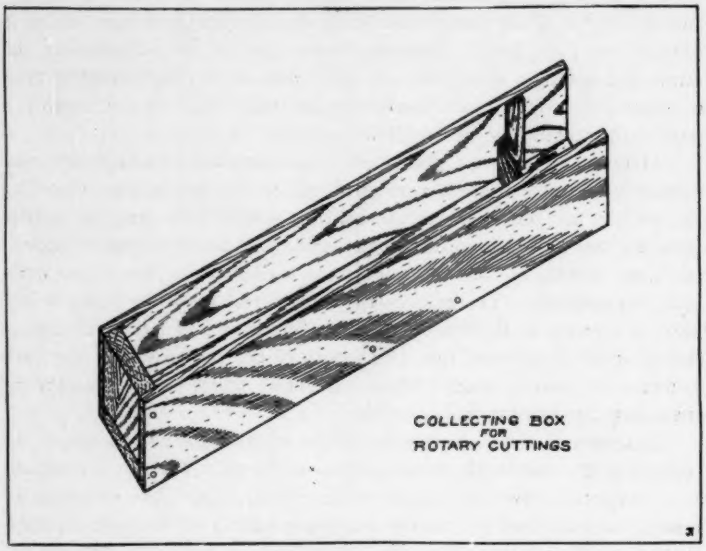

FIG. 1.

hands or a small shovel. The box is then cleaned out by removing the weir and using it to scrape any remaining cuttings out through the open end of the box. Then the weir is replaced and the same cycle repeated for each successive sample.

The location of the collecting box with respect to the return line and the method adopted for diverting part of the slush to it are governed entirely by the conditions existing at the rig. In general, the box should be approximately level, and should be so located as to be readily accessible.

It would be impossible to describe installations to meet every conceivable set of conditions that might be encountered, but the following discussion of a few common installations will serve to show the solution of some of these problems and will no doubt suggest methods of meeting others which may be encountered.

Four typical installations of the collecting box are illustrated in Figure 2. Diagram *A* illustrates in plan view a case in which a wooden flume or sluice box carries the returns and the collecting box is set in the side of the pit embankment, at right angles to the flume, the closed end of the box being placed just below the floor of the flume. Slush is diverted into the box by cutting away a part of the side wall of the flume and nailing a small board at the lower end of this opening so that it extends diagonally into the stream of mud-fluid, thus diverting a part of the stream out through that opening.

Diagram *B* shows a plan view of an installation which can conveniently be used where a wooden flume carries the returns direct to the settling pit, but in which the velocity of flow is so great as to preclude the use of a weir in the flume itself. The box is suspended above the slush stream by two narrow boards, nailed to its closed and open ends, respectively. The ends of the boards rest upon the flume walls. Slush is diverted to the box by a straight length of 2-inch pipe, the upper end of which is inserted into the mouth of the return pipe. For convenience the box is placed where the flume crosses the embankment separating the settling and slush pits.

Diagram *C* shows a side elevation of an installation where an eight-inch pipe carries the returns direct to the pit. The box is mounted on a platform below the mouth of the return pipe. The diversion of slush is accomplished by placing the box in such a position that it intercepts a portion of the stream of slush. By pivoting the box on the platform, it can readily be adjusted to intercept any desired amount of slush.

Diagram *D* shows a plan view of the installation where the slush is emptied into an earthen flume running along the edge of the derrick floor at right angles to the return pipe. The collecting box is placed on the opposite side of the flume. Slush is diverted to it by inserting one end of a piece of two-inch pipe, bent to the proper shape, into the mouth of the return pipe. The other end of the pipe rests in the receiving end of the box. The volume of slush handled by this pipe may be increased by belling out the intake end.

The instances cited will suffice to indicate the general method of procedure in adapting the collecting box to the particular conditions encountered at the well.

It is not claimed that these are the only devices which will successfully collect representative samples, but they have been adopted because of the satisfactory results obtained by their use.

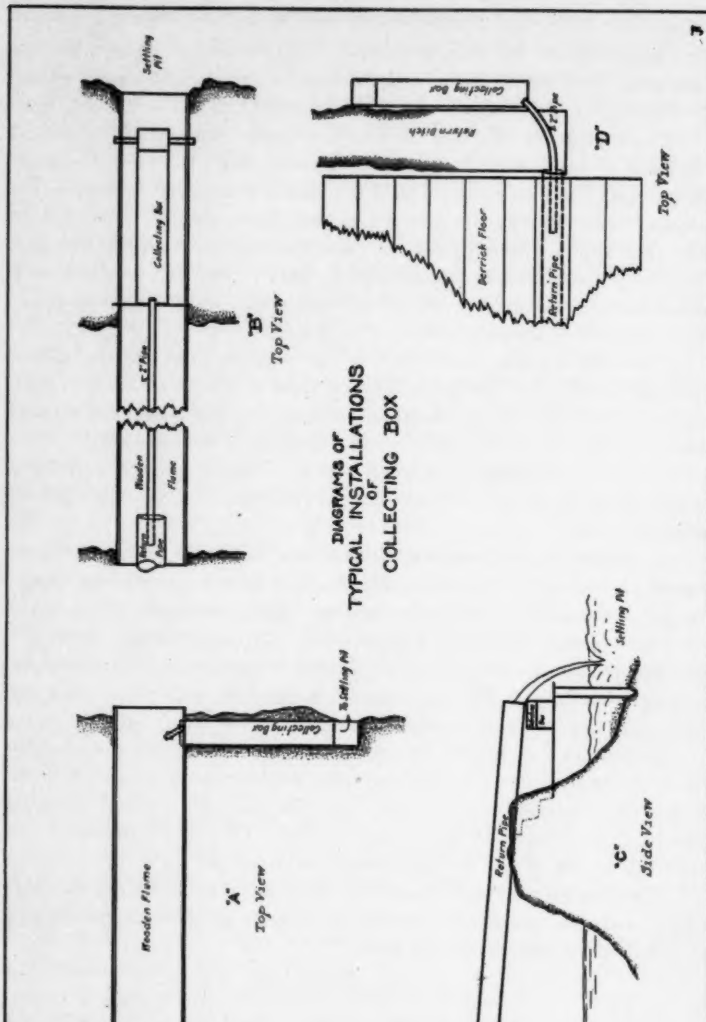
DIAGRAMS OF
TYPICAL INSTALLATIONS
OF
COLLECTING BOX
'A'
Top View
Wooden Flume
Collecting Box
To Settling Pit
'B'
Top View
Settling Pit
Collecting Box
Wooden Flume
'C'
Side View
Return Pipe
Settling Pit
'D'
Top View
Derrick Floor
Return Pipe
Return Ditch
Collecting Box

Fig. 2

Four typical installations of the collecting box are illustrated in Figure 2. Diagram *A* illustrates in plan view a case in which a wooden flume or sluice box carries the returns and the collecting box is set in the side of the pit embankment, at right angles to the flume, the closed end of the box being placed just below the floor of the flume. Slush is diverted into the box by cutting away a part of the side wall of the flume and nailing a small board at the lower end of this opening so that it extends diagonally into the stream of mud-fluid, thus diverting a part of the stream out through that opening.

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The instances cited will suffice to indicate the general method of procedure in adapting the collecting box to the particular conditions encountered at the well.

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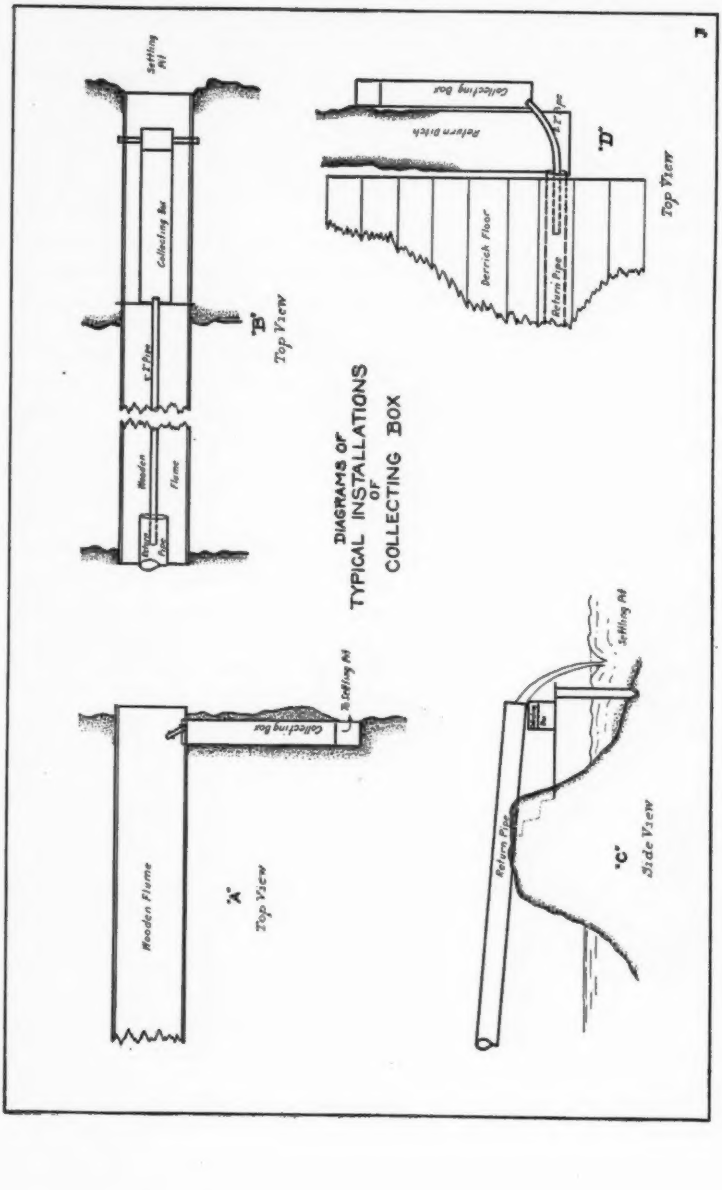
DIAGRAMS OF
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Top View
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Wooden
Flume
Return Pipe
'C'
Side View
Return Pipe
Settling Pit
'D'
Top View
Derrick Floor
Return Pipe
Return Ditch
Collecting Box

Fig. 2

WASHING THE SAMPLES

Regardless of the details of the method by which the samples are obtained, they should all be subjected to a thorough washing immediately after being removed from the collecting device. Especial care is necessary in the washing of rotary cuttings, since each individual fragment of sand, shale, or lime, as it comes from the well, is coated with a heavy film of mud. Unless this film is completely removed it is impossible to distinguish one type of rock from another. Because of that fact, samples which have not been thoroughly washed at the well have to be rewashed in the laboratory before they can be examined. When such rewashing is necessary the time required for the examination of a given set of samples is more than doubled.

The cuttings may be washed in the same manner that cable-tool cuttings usually are, that is, by placing them in a bucket, filling it with water, stirring thoroughly, and pouring off the muddy water, this process being repeated until all traces of the mud have disappeared.

However, with rotary cuttings this is a tedious process and there is a tendency on the part of the "sample grabbers" to slight the washing when it is used.

A special sample washing bucket can be easily prepared which makes the labor of washing negligible, and practically eliminates the danger of having to re-wash the samples. The washing bucket is made from an ordinary heavy-gauge water pail. Several half-inch holes are punched in the bottom of the pail. A circular piece of window screening is then placed upon this perforated bottom and soldered around the edges. In operation the sample is placed in this bucket, and a stream of water from a hose played directly upon the cuttings with considerable force, the wash water and its entrained mud draining off through the screen and the perforated bottom. By this method thorough washing can be accomplished in about one minute. The screen prevents any appreciable loss of the actual cuttings or small fossils.

The washed cuttings should be dried, if possible, before sacking, to eliminate the possibility of steel particles from the bits rusting and staining the cuttings with iron oxide.

DEPTH MEASUREMENTS

Some of the washed cuttings are then placed in a cloth sample bag and tagged for future identification, with the name of the operating company, farm name, well number, location, and the depth measurements corresponding to the top and bottom of that particular sample.

It is obvious that if the final log compiled from such cuttings is to be of any value for subsurface structure mapping, the errors in these depth measurements must be confined within reasonable limits.

There are two possible sources of error in the figures. First, errors in the determination of the depth at which the bit is actually operating, and second, errors due to lag in the returns, that is, the time interval that elapses while the cuttings are ascending from the bottom of the hole to the surface.

The errors in the determination of the drilling depth are by far the more serious. From the nature of the methods of keeping track of the depth, in the respective forms of drilling, it would naturally be expected that the rotary driller's measurements would be more accurate than those of the cable-tool driller. But because of the comparatively slight amount of attention given to rotary logs by geologists and production department officials, rotary drillers in general have developed a negligent attitude toward depth measurements which has resulted in gross errors in their records. A careful check of the measurements of several drilling wells revealed the fact that errors ranging as high as 75 feet were not uncommon in wells which had reached a depth of approximately 3,000 feet. The practice of estimating the length of "fourbles" is responsible for many such errors. The initial error in such an estimate may be comparatively small, but its effect is cumulative and consequently becomes more serious as the depth increases.

The only satisfactory method of obtaining depth measurements is to measure, and record the length of, each joint of drill pipe with a steel tape as it is first run in the hole. As a further precaution it is advisable to check the length of the working "string" of drill pipe at intervals of about 1,500 feet.

With the total length of the drill pipe in the hole accurately determined, the 5- or 10-foot intervals at which samples are to be taken can be checked from the progress of the "kelly joint" and the samples labeled accordingly.

A study of the rates of return of cuttings from the bottom of the hole indicates that the inaccuracies due to lag are relatively slight, under the drilling conditions ordinarily encountered in this state. This would not be true, however, in areas where the rate of progress in drilling was extremely rapid.

A technical discussion of the various factors affecting the rate of return of the cuttings accompanied by tables and formulas may be found in the text book *Petroleum Production Methods* by John R. Suman[1].

For the purposes of this article it will be sufficient to cite the approximate rates of return under normal operating conditions. These are shown in Table I.

TABLE I

Drilling Depths		Rate of Return
From	To	
0	2,500 feet	100 ft. in 45 seconds
2,500	3,500 feet	100 ft. in 1 minute
3,500	3,750 feet	100 ft. in 1 minute 15 seconds
3,750	4,000 feet	100 ft. in 1 minute 30 seconds

A simple calculation at the well based on these figures will readily show whether the error due to lag is of serious proportions. For example: assume that drilling is progressing at a rate of 4 feet per hour (96 feet per day) at a depth of approximately 3,000 feet. The time required for the cuttings to reach the surface will be 30 minutes. In that time the bit will have drilled 2 feet of additional hole. This 2 feet represents the amount of the lag error in the depth measurements of samples taken under conditions mentioned when they are marked according to the indicated drilling depth at the time of taking. Thus, if the baffle is placed in the sluice box when the drilling depth is 3,020 feet, and the sample removed at an indicated depth of 3,030 feet, this sample will actually represent the rocks penetrated from 3,018 to 3,028 feet.

In the example cited, the error is obviously negligible in view of the limits of accuracy of the present methods of determining well depths.

These lag errors are not cumulative, the error in any given sample being governed solely by the time required for its return and the rate of drilling, nor do they tend to become excessive at great depths, for while the return time increases with depth, there is usually a compensating decrease in the rate of drilling progress.

The rate of progress is the dominant factor and, in consequence, the errors are largest in the shale intervals where extreme accuracy is not essential, whereas the hard sands and limes, which constitute the geologists' best "markers," automatically bring the errors down to small proportions by reducing this rate of progress.

[1]Gulf Publishing Company, Houston, Texas.

In view of these facts, and also because any attempt to apply precise corrections to all cuttings would introduce the possibility of large personal errors made by the "sample grabbers," the usual practice is to ignore the element of lag in marking the samples. Corrections on specific horizons can readily be made by a notation on the tag, as "Top of sand at 2,740 feet," as indicated by the behavior of the drill.

THE EXAMINATION AND INTERPRETATION OF THE CUTTINGS

The examination of rotary cuttings differs in no essential from the methods in use for the examination of cable-tool cuttings. In the field a pocket magnifier, from 10- to 16-power, and a bottle of dilute hydrochloric acid are the only equipment necessary. In the laboratory, a microscope (a good binocular microscope fitted with oculars and objectives giving a magnification of 20 diameters makes a very satisfactory instrument), a dropper bottle of acid, and facilities for washing and drying samples, represent the bare essentials.

Since some "rock flour" generally accumulates, even in thoroughly washed samples, as a result of handling and transportation, the examination is facilitated if the cuttings are first dumped into a small 80-mesh sieve and shaken to remove this dust.

The cuttings are then spread out in a thin layer on a piece of heavy paper and a rough estimate is made of the percentages of sand, lime, shale, and other constituents. Fossils, if present, may be picked out for more detailed study (Fig. 3, *A*, *B*, and *C*), and any material the character of which is in doubt may be transferred to the miscoscope stage or tested with acid to establish its classification.

The preliminary description of the cuttings is simply a record of these percentages of the different types of rocks in each sample, together with appropriate descriptions as to color, texture, hardness, and fossil content. Table II shows an example of this preliminary record.

This form of record has been adopted because it makes any abrupt changes of the material contents, in the sequence of samples, apparent at a glance, and experience has demonstrated that it is these abrupt changes which are significant rather than the gross material in the individual sample.

Different wells will not yield precisely similar sets of cuttings of the same geologic sections. This may be partly due to slight differences in the arrangement or efficiency of the sampling devices, but the greatest factor is probably in the efficiency of operation of the settling pits. As a rule, some shale is present in practically all rotary cuttings. Where

FIG. 3.—A. Fossils recovered from rotary cuttings. (Natural size.) B. Microphotograph of *Fusulinae* shown in A, indicating degree of preservation. (Enlarged approximately $\times$ 9.) C. Microphotograph of *Bryozoa* shown in A, indicating degree of preservation. (Enlarged approximately $\times$9.)

TABLE II

PRELIMINARY DESCRIPTION OF ROTARY CUTTINGS

Gypsy Oil Co., Muegge No. 1, Sec. 33, T. 26 N., R. 3 W., Grant County, Oklahoma

Depth in Feet	Per Cent Dark Shale	Per Cent Red Shale	Per Cent Limestone	Per Cent Sandstone
1520–1525	40	60		
1525–1530	40	60		
1530–1535	10	20		70 Fine soft light sand, slightly red
1535–1540	10	20		70 Fine soft light sand, slightly red
1540–1545	35	35		30 Fine soft light sand, slightly red
1545–1550	40	50		10 Fine soft light sand, slightly red
1550–1555	40	50	10 White porous limestone	
1555–1560	30	50	20 White porous limestone	
1560–1565	30	50	20 White porous limestone	
1565–1570	30	40	30 White porous limestone	
1575–1580	30	30	40 Gray sub-crystalline lime	
1580–1585	15	25	60 Gray sub-crystalline lime	
1585–1590	50	30	20 Gray sub-crystalline lime	
1590–1595	60	40		
1595–1600	60	40		
1600–1605	70	30		
1605–1610	70	30		
1610–1615	70	30		
1615–1620	60	40		
1620–1625	60	40		
1625–1630	40	60		
1630–1635	40	60		
1635–1640	40	60		
1640–1645	50	50		
1645–1500	60	40		
1650–1655	70	30		
1655–1660	80	20		
1660–1665	70	30		
1665–1670	60	40	Few fragments light dense limestone.	
1670–1675	10	20	70 Light dense limestone	
1675–1680	10	20	70 Light dense limestone	
1680–1685	15	25	60 Light dense limestone	
1685–1690	50	20	30 Light dense limestone	
1690–1695	50	20	30 Light dense limestone	
1695–1700	20	20	60 Light dense limestone	
1700–1705	45	45	10 Light dense limestone	
1705–1710	20	10	70 Gray shaly limestone	
1710–1715	20	20	60 Gray shaly limestone	
1715–1720	20	20	60 Gray shaly limestone (Plentiful *Fusulina*)	

the settling pits are inefficient this percentage may be very high. In such a well, for instance, the percentage of lime in the samples may never exceed 30 to 40 per cent even where a considerable thickness of solid lime is penetrated, the remaining portions of the samples being shale which has circulated with the mud. But another well with a more effective settling of the rotary mud may yield samples from the same horizon in which the content of lime will run as high as 80 to 90 per cent. Such differences must be taken into consideration by the geologist in his interpretation of the results of his examination, when making up the final log of the well.

The object sought in the preparation of the final log should be a record showing, as accurately as possible, the actual sequence of rocks penetrated by the drill. It is compiled from the information contained in the preliminary description by the following process. An inspection of the record shows, for example, that limestone fragments appear in a certain sample, are present through succeeding samples, and then fail to appear in the next few samples. It is obvious that these lime fragments represent a bed of limestone penetrated by the drill, and its approximate position in the log is evident at a glance. By a comparison of the percentages of lime in the first and last samples in which it appears with the percentages found in the intervening samples, a reason-

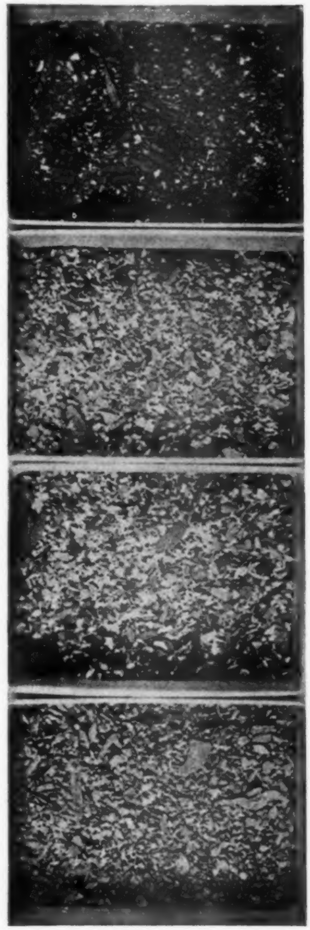

FIG. 4.—Samples from Marland *et al.*—Lemon No. 1, Sec. 10, T. 19 N., R. 1 W. Depth, 4,200 to 4,220 feet. A sequence of samples of rotary cuttings taken at 5-foot intervals, showing a transition from black shale to white lime and back to dark shale.

ably accurate estimate can be made of the exact depths at which the top and bottom of this lime were encountered.

Figure 4 shows photographically such a sequence of samples. These samples were taken at 5-foot intervals. The uppermost sample is practically all black shale, though a few small fragments of white lime are present. The two succeeding samples contain about 80 per cent of white lime, but in the fourth sample the lime drops to 20 per cent. The last change is not so evident in the photograph due to the fact that the shale found below the lime is not as dark as the one above it and consequently does not afford as great a contrast.

The preliminary description gives the same perspective of long sequences of cuttings as this photograph does in this short series through a 12-foot bed of limestone.

By repetition of the previously described process, all the contacts between the sands, shales, limes, gypsum, and other units, can be determined, and with somewhat less accuracy the contacts between shales of different colors and characteristics can be located. The assembled data thus obtained constitutes the final log (Table III).

TABLE III

FINAL LOG FROM ROTARY CUTTINGS

Gypsy Oil Co., Muegge No. 1, Sec. 33, T. 26 N., R. 3 W., Grant County, Okla.

DEPTH IN FEET	FORMATION
1520–1530	Red shale
1530–1550	Fine, light, soft, slightly reddish sand
1550–1575	White, porous limestone
1575–1590	Gray, sub-crystalline limestone
1590–1625	Dark shale
1625–1640	Red shale
1640–1670	Dark shale
1670–1705	Light, dense limestone
1705–1720	Gray, shaly limestone. (Plentiful *Fusulina*.)

The final record is identical in form with the ordinary driller's log and like it may readily be converted to graphic form.

TESTING SANDS FOR OIL CONTENT

In addition to the regular examination of the cuttings as previously described, it is highly desirable to make a supplementary test for oil

content of the cuttings from any sands which are regarded as possible sources of production.

Tests with any of the ordinary solvents may serve for this purpose in areas where only oils of low gravity and dark color are to be expected. But they are generally unsatisfactory if oil of high gravity and light color are involved, because the coloration is apt to be so slight as to be completely obscured by any fine particles going into suspension in the liquid.

The most satisfactory test thus far devised for the determination is a simple distillation test. The only equipment necessary is a Bunsen burner or alcohol lamp, a test tube holder, and a supply of small test tubes.

The process is as follows. From the sample to be tested, several fragments of the sand, sufficient to furnish the necessary charge, are picked out and inserted in a test tube. Care should be exercised that no shale fragments are included, as many shales contain bituminous material which can be converted to petroleum by the distillation process. The size of the charge need not exceed a few grams.

The bottom of the test tube containing the charge is then inserted in the Bunsen burner flame, where it is allowed to remain until the distillation is complete. While the distillation is going on the test tube should be held in an approximately horizontal position, with the mouth of the tube slightly lower than its bottom, to prevent any of the condensate from running back onto the heated portion of the glass. If the charge contains oil it will be distilled off in the form of a dense white or yellowish vapor. As it reaches the cooler portions of the tube, this vapor will gradually condense, thus leaving the oil in small drops upon the sides of the test tube.

Before being accepted as a dependable test for use on wildcat wells, this method was given a thorough trial under known conditions during the development of the Retta field in western Kay County, Oklahoma, by testing sand cuttings from rotary holes which were twins to cable-tool wells. This afforded an ideal opportunity to check the results obtained by this method of testing with the information already furnished by the cable tools.

The results of these experiments were wholly satisfactory. The tests consistently revealed the presence of oil within known productive areas. In addition, it was found that by taking samples at smaller intervals than the customary 10 feet, the actual thickness of "pay" sand,

that is, the oil-saturated sand penetrated before the water-bearing portion of a sand was reached, could be determined with reasonable accuracy.

The presence of the oil was revealed just as conclusively in the case of holes which were twins to edge wells producing 50 barrels or less, as it was in areas of more prolific production.

The basic fact which is responsible for the success obtained in testing rotary cuttings for the presence of oil, is apparently the mode of operation of the "rock bit." It has essentially a chipping action in contrast to the pounding or pulverizing action of the cable tool bit. As a result, instead of reducing the sandstone to its individual grains, or small clusters of grains, the rotary bit chips off small fragments of the rock which, except in the matter of size, are comparable with the larger specimens obtained by coring. As a further aid to the geologist, each chip, as it is removed from the parent rock, is enveloped in a protective coating of the rotary mud, thus preserving the original contents within the pore space of that particular fragment and precluding the possibility of its absorbing any appreciable quantity of oil or water from other sources, prior to its delivery at the mouth of the well.

In contrast with the practice of coring to test sands for oil content, the method has the advantages of offering no hindrance whatever to the progress of drilling, of involving only a slight expense for the collection and testing of the cuttings, and of furnishing accurate information in respect to the entire thickness of sand penetrated.

Occasional short cores taken at intervals through a sand body are not only expensive but yield only fragmentary information, since they indicate nothing whatever as to the character and contents of the uncored portions.

Continuous coring would of course give even more satisfactory information than that obtained from the drill cuttings. In some areas it may be wholly feasible. But where the well-consolidated sands of the Pennsylvanian or older rocks are involved, the cost is practically prohibitive with the equipment ordinarily available.

Modification of the present rotary equipment to permit the use of the diamond drill for coring hard sands may alter this situation, but even in that event the examination of the cuttings, if made at the well, would be a valuable aid in determining where to core.

CONCLUSIONS

The ultimate goal of the work which is now being done in logging rotary wells from cuttings is, of course, the improvement of all rotary logs, rather than the accurate logging of a few selected holes.

Judging from the interest displayed by the drilling crews and contractors who have been involved in the experiments made thus far, it seems reasonable to predict that within a few years the drilling crews will catch samples as a matter of routine, and base their logs primarily upon an inspection of these cuttings.

Examples are already on record in which crews who had worked on a well or two sampled by the geological department, have gone into areas with which they were not familiar and by sampling the returns, wholly on their own initiative, have produced logs comparing favorably with cable-tool logs.

Contractors have been quick to see the possibilities for increasing the value of their services, and at least one promoter of wildcat wells has adopted continuous sampling of his wells as a means of increasing the salability of his acreage.

If this article operates to hasten, in some degree, the general use of cuttings as the basis for rotary logs, by detailing the methods used for the benefit of geologists not already acquainted with them, and by indicating the benefits to be derived to production officials, promoters, and contractors, it will have fully served its purpose.

TECHNICAL PAPERS AND THEIR PRESENTATION[1]

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ABSTRACT

As a rule not enough care is exercised by authors in the preparation and presentation of their technical papers. The writer offers definite advice for satisfactory oral delivery such as sufficiently loud and distinct speaking and direct address to the audience. He discusses the proper use of displays, giving special attention to the preparation of drawings and lantern slides. In general, the speaker should talk directly to his audience and so loudly and distinctly that those on the last row can hear him. His displays should be free from confusing detail and possess good visibility. In preparation of illustrations for the printed page, all lines and lettering should be made large enough to retain legibility in the necessary reduction.

One of the objects of this Association is to disseminate knowledge. This is done through papers and discussions. The thought and care exercised in the physical preparation and delivery of these papers and discussions is not always consistent with the efforts put upon the text. If drawings, charts, maps, or other displays are not well prepared and if the delivery of the papers at a meeting is not good, then the qualities of the text will suffer.

PREPARATION FOR DELIVERY

Real preparation is necessary for the proper delivery of papers at meetings. An author's paper suffers in proportion to the suffering of his audience through poor delivery.

The first step in this preparation for delivery is to become familiar with the final draft of the paper by several readings. If there is any question as to the proper phrasing, the paper should be read aloud. Use short sentences. The average paper has sentences which are uniformly too long for oral reading.

The second step is the preparation of good drawings, maps, or other display to be used in connection with the delivery. Lantern-slide projections are the most practicable. Drawings, charts, or maps

[1]Manuscript received by the editor, October 28, 1927.

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which are suitable for direct display to an audience must be very large and their preparation and transportation are difficult.

Good preparation requires also that the direct display shall be in place before the session starts.

DELIVERY

Very few who undertake to deliver papers are unfamiliar with the principles of good delivery. The majority have attended meetings and have noticed the good and bad points in the delivery of others. Nevertheless, certain principles are violated by speakers, again and again. Part of this poor delivery may be traced to poor preparation. Much blame may be placed upon pure thoughtlessness. It is not necessary to be a trained public speaker to present a technical paper.

If either lantern-slide projections or direct displays are to be used, the speaker should remember that the audience can read. If the display has been properly prepared, the audience can read faster than the speaker can read for it.

By far the best method of discussing any display is to have a copy of such display at the proper place in the author's manuscript and to speak from this copy and not from the display. Pointing to and reading from display should be reduced to a minimum. Properly prepared display would eliminate a great deal of indiscriminate reading and pointing. Nothing holds the attention of an audience better than good display.

It is obvious that good delivery requires that the author shall face the audience and not the display, while speaking. If the speaker must point, he should point first and then turn his face toward the audience to speak.

The majority of speakers at technical sessions do not talk loudly enough. They address their remarks to the front rows with the result that the majority of the audience have difficulty in hearing. The best method of delivery is to pick out a row in the rear of the audience and to address this row. Talk to the rear of the house.

PREPARATION OF DRAWINGS, CHARTS, OR MAPS

Drawings, charts, or maps form an essential part of the majority of technical papers. In spite of their importance, too many drawings are made with but little thought as to how they will lend themselves to standard methods of reproduction. The appearance of drawings in any technical paper is the first thing which impresses the reader. They

are in the nature of an advertisement. As much time and effort should be given to them as is consistent with the paper which they accompany. Many good technical papers are ruined by poorly presented drawings.

It is seldom that drawings, charts, or maps which have been prepared for other uses, are fit for presentation in technical papers. Shop drawings of appliances which have been prepared for production are commonly useless for publication in connection with a description of the appliance. Few maps which are made for general office use meet the needs of a technical geological writing. Drawings, charts, or maps should be specially prepared so that they will meet the specific needs of the paper at hand and in addition will lend themselves to good reproduction.

Lantern-slide projections are essential for the efficient presentation of many technical papers. Many drawings prepared with regard to the requirements for good printing reproduction will make good lantern-slide copy, but not all drawings will. This is because the ratio of height to width of page in most technical bulletins is reversed in the lantern slide and long, narrow drawings, which fit exactly the printed page, will not fit the lantern slide.

LANTERN-SLIDE COPY

Lantern slides are 3¼ inches vertically and 4 inches horizontally and the proportion of approximately .8 to 1 should be borne in mind in making slide copy. The size of the actual image on a lantern slide is not 3¼ inches × 4 inches because of the border mat and binding which are necessary. The maximum practical dimension of image is about 2⅝ inches × 3¼ inches.

It is desirable to have the projected picture visible to the entire audience. The maximum distance from any member of the audience to the screen varies widely but this maximum distance determines the necessary visibility of the projected picture. Visibility, in turn, determines the character of the copy to be made.

The maximum audience distance of about 50 feet is the approximate limit of small lecture rooms such as are found in office buildings, hotels, and technical societies. A 100-foot maximum audience distance is the approximate limit for ordinary auditoriums in which technical meetings are held.

It is practical to show lantern-slide projections for maximum audience distances beyond these limits but the subjects are limited to

photographs in which there is very good contrast, to drawings which are simple bold outlines, and to a few lines of very bold lettering.

Motion pictures have familiarized everyone with the character of photographs which will project with good visibility. Motion picture titles have furnished examples of what is necessary for simple text. It is in the realm of charts, maps, drawings, and the like that those inexperienced in the production of lantern-slide copy require some guidance.

As far as the projection of the slides in question is concerned, good visibility means that the lines on the screen shall stand out as individual, unbroken, straight black lines. This visibility is a function of the brightness contrast and the resolving power of the eye.

DIMENSIONS FOR MAXIMUM VISIBILITY

It is not necessary to explain here the experiments and calculations used in arriving at a formula for the minimum line to be used in lantern-slide copy. Experimenters agree closely on the fundamentals from which the following formula has been derived.

$$m = .00015\frac{Ac}{P}$$

m = Maximum width of line in inches for a width of copy, c
A = Maximum audience distance in feet
c = Width of copy in inches
P = Width of projection in feet. (Usually about 80 per cent of the width of screen.)

NOTE: When the height of copy is more than 0.80 of the width then

$c = 1.25$ height of copy and not width of copy.

The visibility of parallel lines which are close together is about half of that of a single line with a wide, contrasting background. This is of interest because it determines the approximate minimum size of lettering and width of line for lettering.

The minimum line used in forming letters should be twice the thickness of the minimum single line as found from the foregoing formula.

The height of letters should be at least five times the thickness of the line used to form the letters, no matter what may be the thickness of the lines forming the letters.

The space between letters or lines of lettering should be at least equal to the thickness of the lines forming the letters.

Columns of figures should be spaced at least four times the thickness of the line forming the figures.

Lines composing the ruling for charts may be made ¾ the width of the minimum single line and should be at least ½ the width of any line drawn on the chart. It is not necessary or desirable that rulings on charts shall have 100 per cent visibility. It is more desirable that these lines shall be inconspicuous.

TYPEWRITTEN COPY

The impression made by a typewriter appears, to the naked eye, to be a continuous ink impression. However, when magnified, the impression is found to be a series of irregular blotches made by the threads of the typewriter ribbon upon the irregular surface of the paper. This is the reason that typewriter copy makes very poor lantern-slide copy.

The use of the typewriter should be avoided in lettering charts or drawings or in making columns of figures.

CONTRAST

While the minimum line may determine good visibility, copy which is made up of lines of uniform width will be difficult to read when projected. There should be considerable contrast between appropriate lines in order that the eye may pick out the essential features readily.

JUDGING COPY

The approximate visibility of slides or copy may be judged by holding at a distance from the eye as determined from the following formula:

$$e = \frac{cA}{P}$$

e = Inches from eye to slide or copy
A = Maximum audience distance in feet
P = Width of the projection upon the screen
c = Width of copy in inches

NOTE: When the height of copy is more than 0.8 of the width then c = 1.25 height and not width of copy.

NEGATIVE SLIDES

Visibility is a function of brightness contrast and the resolving power of the eye. If lantern slides are made as black lines on a transparent background, the amount of light reflected from the screen gen-

erally causes a glare, with the result that the retina opening is contracted and visibility is reduced. Slides made with white lines on a black or reduced background cut down the amount of reflected light without reducing the brightness contrast, and visibility is better for the same thickness of line. Dark-background slides are recommended as being more visible and less tiring to the eye.

LANTERN SLIDES IN GENERAL

The formulae for minimum dimensions are given as guides and *not* as rules. The lines on copy should be as thick as is consistent with the matter to be presented. Good copy must be clear and plain.

Original lantern-slide copy should be small. An 8½ inch × 11 inch sheet is large enough for almost all copy. Anything which cannot be clearly drawn upon an 8½ inch × 11 inch sheet is ordinarily too complicated for a single slide.

Glossy-surfaced paper should not be used for lantern-slide copy. Use the dull surface of tracing linen.

PRESS REPRODUCTIONS AND PRESS COPY

The principles of visibility which apply to lantern-slide projections also apply to "cuts," that is, to press reproductions of drawings, charts, or maps.

The maximum cut which may be presented in the *Bulletin* of the Association is 4¼ inches wide and 7 inches high, unless a special, folded insert is made. This ratio (1 to 1.65) should be borne in mind in making copy for the *Bulletin*. It is desirable to have cuts stand with the type whenever possible. This means that copy for such cuts must have good visibility if reduced to a width of 4½ inches.

DIMENSIONS FOR GOOD VISIBILITY

With a reading distance of 12 inches, the minimum dimensions for good visibility of cuts in the *Bulletin* are:

Single line — 0.002 inches
Line forming letters — 0.004 inches
Height of lettering — 0.01 inches
Ruling on charts — 0.0015 inches

The minimum dimensions of lines and lettering for any width of copy is proportional to the size of the copy.

$$\frac{\text{Width of reproduction or cut}}{\text{Width of copy}} = \frac{\text{Reading distance minimum dimensions}}{\text{Dimensions of lines on copy}}$$

As in the case of lantern-slide copy, these minimum dimensions are given as guides and all lines should be as thick as is consistent with the material to be presented and with the proper attention paid to contrast in the thickness of appropriate lines.

Typewritten material may be reproduced for press printing with somewhat better results than in the case of lantern slides but the results are never entirely satisfactory. Most typewriter inks are deep blue and not black and do not photograph well, especially if the ribbon is worn.

Copy for cuts is ordinarily made too large. It is an advantage to make large copy because imperfections are minimized by reproduction. On the other hand, there is always a tendency to make the details on large copy so complicated that they do not reproduce readily. There is also a tendency to use lines and lettering which will be too small if reduced. It is better to make copy as small as is consistent with the matter being presented unless calculations have been made to determine the minimum dimensions for good visibility and unless these dimensions are carefully followed.

GEOLOGICAL NOTES

LOSS OF COLOR OF RED SANDSTONE UPON DEPOSITION

The problems of red-bed sedimentation are of interest to every geologist working with sedimentary rocks, and especially to those in the southwestern part of the United States where Pennsylvanian, Permian, and Triassic red beds form a conspicuous part of the geologic column. At several meetings of this Association, and at informal gatherings of geologists, the question "Why are the red beds red?" has been propounded; and although it is a question of long standing, and much has been written in an attempt to answer it, the diversity of opinions expressed in the discussions it arouses, indicates that the correct solution may not yet have been found. A satisfactory answer to this question will be more readily obtained when there are more descriptions of actual examples of red-bed sedimentation taking place in contemporary time. This note describes an example of the loss of red color by an originally red sandstone upon re-deposition, and cites a similar occurrence during the deposition of the Pico formation, of Pliocene age.

Immediately north and west of the town of Ventura, on the California coast between Los Angeles and Santa Barbara, the Oligocene(?)-Miocene Sespe red beds outcrop extensively in the mountains, the nearest outcrop to the ocean being about two miles from it. Several streams, most of them intermittent streams with steep gradients, rise in, or flow through, the areas of Sespe outcrop and transport many boulders and pebbles of red sandstone down to the beach.

These fragments are strewn along the beach at various places, and are especially concentrated at Rincon Point, Punta Gorda, and Pitas Point. About an equally large proportion of them are not red throughout, but partially or wholly rusty brown, yellowish-buff, light green or greenish-gray, and the grayish-buff of the unstained mineral constituents of the rock. An individual boulder may show any one of these colors throughout, or may show a gradation from red in one part through the intermediate color stages to greenish-gray and grayish-buff in another part. The green color is commonly restricted to the outer quarter or half inch of a boulder, the inside of which is red. Where rock borers have pitted the surface of such a boulder, the green shell extends deeper around the holes. The conclusion indicated by these

observations is that the fragments of red sandstone which retain their color during transportation to the beach, are there subjected to conditions which alter the color progressively from red to limonitic brown, to yellowish-buff, to light green, to greenish-gray and grayish-buff.

In their positions along the beach these pebbles are alternately submerged when the tide is in and exposed to the atmosphere when the tide is out, but probably are never completely dry. Some of them are covered with sea anemone, cap limpits, algal growths, and barnacles (Fig. 1),

Fig. 1. Red sandstone boulders covered with cap limpits, barnacles, sea anemone, and algal growths. Pitas Point, California.

and the beach is at places strewn with organic remains such as seaweed and shellfish. Hence the waters are probably charged with carbon compounds and natural organic acids from the vital processes and decay of so many organisms.

The red color of the Sespe sandstone proved upon analysis to be hematitic ferric oxide staining the grains and matrix. The continued wetting of the sandstones without thorough drying would hydrate the ferric oxide stain from the red hematitic state to the brown limonitic state, changing the sandstone from red to brown. The reducing action of the organic solutions[1] in the sea water would reduce the brown ferric oxide to the greenish ferrous state. Carbonic acid solutions would then leach away the ferrous salts[2] and leave the unstained mineral constit-

[1]Fred R. Neuman, "Cretaceous White Clays of South Carolina," *Econ. Geol.*, Vol. XXII (1927), pp. 383-84.

[2]Fred R. Neuman, *idem*.

uents, the aggregate color of which varies from a light gray to grayish-buff, depending upon the relative abundance of biotite.

In a more lengthy paper the writer[1] shows that the Sespe formation was an important source of the detrital material composing the younger Pico formation (Pliocene). Yet there are very few sandstone pebbles in the Pico conglomerate showing as much as a trace of red color. The conclusion reached is that the sandstone pebbles were subjected to processes similar to those here described, and had lost their red coloration before deposition.

LON D. CARTWRIGHT, JR.

COLORADO, TEXAS
October 23, 1927

POSSIBILITY OF FUSING OIL SANDS WHEN SHOT

In the Mid-Continent and eastern fields where oil sands are frequently shot with high explosives there is a prevalent opinion that they may be and frequently are "burned" or fused. The common conception of this reaction is that the heat of the explosion fuses and seals the sand next to the shot, thus preventing the flow of gas and oil into the well.

Because of the importance shooting may have in the history of any well, some data have been collected concerning the reaction that takes place in an explosion, the time element of the reaction, the conditions under which the reaction takes place, and the fusion point of various types of sands, to determine whether fusing can occur, and if so under what conditions.

Oil sands in the Mid-Continent and eastern fields are composed of quartz sand, limestone, and magnesian limestone or different mixtures of these rocks. Some sands are predominantly quartz but contain other rock-forming minerals, generally of the more resistant type. The nearly pure quartz, limestone, and magnesian limestone sands are the predominating type. As to texture, porosity, and hardness, they differ as do all rocks; however, these properties are not considered in this discussion but should be considered in an experimental and more detailed study.

Due to the variability of composition, the actual fusion point of any one of the rocks which may compose an oil sand can be determined only

[1] L. D. Cartwright, Jr., "Sedimentation of the Pico Formation in the Ventura Quadrangle, California." In preparation for publication in the *Bulletin of the American Association of Petroleum Geologists*.

by test. However, the fusion points of quartz, calcium carbonate, and magnesium carbonate are constant within experimental limits. Liddel[1] gives the melting point of silica as 1,750° C. and calcium oxide as 2,572° C. Mellor[2] says magnesium oxide fuses at about 2,000° C. The melting point of calcium oxide is given by J. C. Olson[3] as 2,570° C., magnesium oxide 2,800° C., amorphous quartz or silica 1,600° C., and crystalline quartz 1,710° C. Neither magnesium nor calcium exists as an oxide in oil sands, but as a carbonate, and before a magnesium or calcium carbonate can be fused, it will first be decomposed to the oxide. Calcium carbonate decomposes at 825° C. and magnesium carbonate at 425° C.

Calcium oxide or magnesium oxide in the presence of quartz acts as a flux to lower the fusion point of the combination or mixture. At 150° C. calcium oxide and quartz intimately mixed will react to form calcium silicate; in other words, the calcium oxide and quartz are fused. Although the fusion point of a magnesium oxide-quartz is not known by the writer, it is probable that it is much lower than that of either alone. Before either of these combinations results, however, it is necessary that the carbonate be decomposed to the oxide which, as previously stated, occurs at a much higher temperature.

Concerning the actual temperature which is developed in the combustion of different kinds of explosives, little is known. W. H. Ward[4] states that "it is safe to say that the temperature of the explosion of any of the well-known nitro-glycerine explosives does not exceed 3,000° C." The calculated temperature to which the products of different kinds of explosives can be raised during the explosion is given by Colver[5] as follows: nitro-glycerine 3,470° C., blasting gelatine (7 per cent cotton) 3,540° C., and black powder 2,770° C. It appears reasonably certain that the temperature of the explosion of any kind of explosives used in oil-well shooting is high enough to fuse any of the rocks which compose oil sands provided the necessary material and time conditions are such as to permit fusion.

The fundamental reaction that takes place when an explosive is ignited or detonated is its decomposition or the reaction of its components, almost instantaneously welding a very large volume of highly

[1] *Metallurgists' & Chemists' Handbook*, pp. 445-46.

[2] *Modern Inorganic Chemistry*, p. 339.

[3] Van Ostrand's *Chemical Annual*.

[4] Personal communication. E. I. du Pont de Nemours Company.

[5] Colver—*High Explosives*.

heated gas. The sudden release of the large volume of gas is the energy of the explosive. When closely confined in the well by a long column of fluid the effect of the release of the energy will be greater than when confined by a short fluid column. With any given explosive, the conditions and method of confinement and release of the energy control the results of the explosion. Part of the heat developed in the release of the gas is very quickly absorbed by the rapid expansion of the gas, thus reducing its effectiveness. The greater the retardation of the expansion of the gas, the longer will be the duration of the temperature. In well shooting the escape of the gas is upward, confined only by the fluid in the hole, the resistance of which is relatively small, as is shown by the rapid escape of the fluid and gas from the well.

The number of quarts of explosive in a well is not a correct basis on which to estimate the amount of effective heat developed or, in other words, to determine the probability of fusion. It is not necessarily true that the larger the shot the greater the probability that the sand will be fused. This depends on two factors: (1) the diameter of the hole, and (2) the length of the shot. For example, if 50 feet of sand is shot, more explosive is used than for 20 feet of sand, the diameter of the shell being the same; for the same amount of sand a 4½-inch shell will contain less explosive than a 5½-inch shell. A more nearly correct basis for an estimate of the effect of the shot would be the number of quarts per foot of sand. It is not true, therefore, that a 100-quart shot in a 5-inch shell 26 feet long will develop twice the effective heat per foot of sand that a 50-quart shot in a 5-inch shell 13 feet long will develop, as the number of quarts per foot of sand is the same in each case. Two quarts of explosive per foot of sand liberates twice as great a volume of hot gas as one quart per foot, but the temperature of the liberated gas is no higher. The use of two quarts per foot of sand permits a greater volume of hot gas to affect the sand than a smaller quantity; however, because of the tremendous amount of gas liberated in either case in comparison with the insignificantly small volume of the hole and because the temperature of effective heat in each case is the same, it is not believed that the temperature of the sand, when two quarts per foot is exploded, is raised more than a few degrees higher than when one quart per foot is used. For all practical purposes the effect of the heat in either case is about the same.

Undoubtedly a very high temperature exists in close contact with the sand at the time the shot is exploded, but only for the briefest instant. The effect of this heat on the sand is similar to passing some

substance of low ignition or fusing point rapidly through a hot flame without its being ignited or fused. Thus the time which this high temperature exists in contact with the sand is too small to permit the sand to be fused.

To what maximum temperature sands may be raised by shooting is unknown. However, some indication of this may be had by measuring the temperature of sand which is bailed from the well immediately after the shot. In several cases observed this has not exceeded 90° C. and it is doubtful whether the temperature of the sand adjacent to the shot is ever much higher than this.

It would appear that quartz, calcium carbonate (limestone), magnesium carbonate, or calcium-magnesium carbonate ("dolomite") sands have such high fusion points that the probability of their being fused is very small. On the other hand, a siliceous limestone or siliceous magnesian limestone will more probably fuse because of the fluxing action the calcium or magnesium carbonates have on silica. Before this fluxing reaction can take place, however, the carbonate must first be decomposed to the oxide.

Another point worth consideration in the possibility of fusing a sand is the shattering and loosening effect of the shot on the sand. If the maximum effect of the heat occurs at the same time as the maximum effect of the energy, and it appears that such is the case, that part of the sand which might be fused by the shot will be shattered and broken loose and removed from the well.

The failure of many wells to meet expectations after shooting is attributed to the shot, and this in turn to the fusing of the sand. There are many other ordinary and more plausible reasons for this failure than fusing. In fact fusing should be last considered in determining the reasons for the failure of a well to respond favorably to shooting. Whether oil sands are fused or are capable of being fused when the ordinary conditions prevail can be actually determined only by special methods of experimentation. However, after considering the problem from all angles it is concluded that the possibility of fusing any of the ordinary types of oil sands found in the Mid-Continent and eastern fields when shot with either large or small amounts of any of the common explosives is very small and that for fusion to take place at all requires very special conditions which rarely exist in the well. The writer has examined

many samples of different types of sands that have been shot, none of which were fused.

JOHN R. REEVES

EL DORADO, KANSAS
October 26, 1927

DIAMOND DRILLING AGAINST HIGH GAS PRESSURE IN TURNER VALLEY, CALGARY, ALBERTA

Drilling down to and into the deep reservoir limestone in Turner Valley is characterized by the following conditions: (1) great depths, (2) alternate soft and hard strata steeply inclined, (3) very hard, metamorphosed reservoir limestone, (4) high gas pressure, and (5) freezing effect of the expanding gas.

These conditions are the most difficult to be found anywhere in the world.

All the wells in Turner Valley have been or are being drilled with cable tools, with the exception of two Royalite wells and one Dalhousie well that are being drilled with standard rotary equipment, another well of the Royalite company drilled under this system having been abandoned because of the crookedness of the hole.

The Illinois-Alberta well has been completed into the reservoir limestone by a diamond drill, but unsatisfactorily, as the $5,000.00 diamond bit is still frozen in at the bottom of the hole. A big F. K. Sullivan diamond drill is boring into the limestone toward the dolomitic reservoir at the Dalhousie No. 1 well.

It is now admitted that both the cable-tool and standard rotary systems are unsuitable to meet adequately the difficult drilling conditions of the Turner Valley field.

It is impossible to overcome successfully the high gas pressure with the cable-tool system, as the tools are blown up in the hole before the well can be brought in properly. This system is also deficient in that successful drilling is endangered through frequent fighting of cave-ins and losses of tools, as testified by the number of abandoned junked holes of Turner Valley. There is, besides, the inconvenience of much time lost in bailing at great depths.

That the rotary equipment is entirely appropriate for very deep drilling is proved by the fact that in the California fields, characterized, it is true, by soft young formations, wells approaching 8,500 feet in depth have been drilled successfully under that system. It has also

the advantage that at a certain depth the column of circulating fluid may be expected to hold down the gas pressure, as shown by the following table:

TABLE I

Depth in Feet	Pressures in Pounds per Square Inch for		
	Clear Water (Specific Gravity 1.00)	Mud-Laden Water (Specific Gravity 1.20)	"Baroid"-Laden Water (Specific Gravity 2.00)
3,740 (Royalite No. 4)	1,615	1,938	3,230
4,000	1,728	2,073	3,456
5,000	2,160	2,592	4,320
6,000	2,592	3,110	5,184
7,000	3,024	3,628	6,048
8,000	3,456	4,147	6,912
8,500	3,762	4,406	7,344

The rock pressure of the dolomitic reservoir is still unknown, but it is certainly higher than the pressure of 2,500 pounds that characterizes the flow of Royalite No. 4 well, which is fed through tiny fissures in the zone of shattered limestone separating the bottom of the well from the true dolomitic reservoir. If that pressure were 3,000 pounds the table shows that it would be overcome by the column of mud-laden water at a depth of about 6,000 feet, and by the column of "baroid"-laden water at a depth greater than that of the Royalite No. 4 well. But it seems to be practically impossible to drill a sufficiently straight hole with the standard rotary equipment through alternately hard and soft, steeply inclined strata, and, furthermore, it is inadequate to penetrate the hard, metamorphozed reservoir limestone or to drill against a gas pressure exceeding the weight of the column of circulating fluid.

It seems that the combination of cable-rotary equipment would be a proper means to reach the deep limestone, the cable tools to be used to a depth of about 3,000 feet, in order to secure a straight hole and also afterward, where the strata would be too hard for the rotary bit. But neither the rotary nor the cable tools would be suitable to drill into the reservoir limestone for the reasons already stated.

It seems thus that there is only the diamond drilling system available with which to venture to bring in successfully a genuine, producing well in the true dolomitic reservoir.

The heaviest Sullivan diamond drill, which is the type F. K., is designed to drill a four-inch hole to 5,000 feet, but has completed to a depth of 6,007 feet a hole in India that had been abandoned at a depth of 4,300 feet by a combination standard-rotary rig. The F. K. machine completed the well in about 75 drilling days, bottoming a 4-inch hole. That far greater depths can be reached with the F. K. machine is proved by the fact that in Africa (near Johannesburg), a 6,700-foot hole has been drilled with one of the smaller Sullivan machines. It is also proper to mention that as early as 1909 the Imperial German Government drilled with a diamond drill a 7,347-foot hole near Czuchow, Upper Silesia, Germany. Considering that depths of nearly 8,500 feet have been attained with the standard rotary equipment, there is no reason why such depths, or even greater depths, could not be attained with the diamond drill.

It may be interesting to consider somewhat the factors that may limit the drilling depth capacity of the diamond drill. Such limitation seems to lie primarily in the stress which is put on the engine and drilling rods by the rotation of the heavy mass of steel and also by the heavy friction developed by the rods on the casing if the hole is not sufficiently straight.

The importance of the factor of stress on the engine is considerably mitigated by the fact that it has to be considered only in connection with the power required for hoisting the drill pipe out of the hole, and not at all as far as rotating power is concerned. Indeed, the steam engine of 8×8-inch with which is powered the F. K. machine, has ample power to rotate a diamond bit at any depth, the power to rotate the drill pipe and bit increasing but very little with depth. This is due to the fact that almost the whole weight of the drill pipe is supported by the drill at the surface, the weight on the bit being regulated so as to have the bit exerting the required pressure on the bottom of the hole, which pressure is comparatively small, (about 1,000 pounds) for safety of operation as well as economy of diamond wear. In fact, it takes less power to rotate a 4-inch diamond bit at 5,000 feet than it does to rotate a 10-inch fish-tail bit at 50 feet. It may be proper to point out that almost the whole of the drill pipe being supported by the hydraulic piston, gravity tends to hold the drilling string in true line, and for this reason the diamond drill is well adapted to drilling a straight hole in formations where there are alternate hard and soft beds dipping off steeply, as is the case in the Turner Valley field.

The limitation of the engine is thus caused exclusively by the increasing weight with depth of the drill pipe to be hoisted from the hole. But this limitation is itself greatly lessened by the fact that the transmission gearing gives three speeds for the hoist as well as for rotating the bit, and that by multiplying the lines in the derrick the drill could pull the drill pipe from a very deep hole. It seems, however, that for very deep drilling, the pulling of the drill pipe should be accelerated by using a more powerful engine, or even by using a separate hoisting equipment sufficiently powerful. It is interesting to note that the Stone Drill Corporation is using now a $10 \times 12\frac{1}{2}$-inch engine giving double the power of an 8×8-inch engine and is designing larger equipment for a 12×12-inch engine that will have 75 per cent greater power than the machine equipped with a $10 \times 10\frac{1}{2}$-inch engine.

It may thus be stated that, in last analysis, the limitation in drilling depth capacity lies in the tensile strength of the drill pipe, and as in California strings of drill pipe nearly 8,500 feet in length have been used with the standard rotary system, it is safe to conclude that by making the drill pipe out of the highest grade of material available and making good, efficacious joints, depths of 8,500 feet could be reached safely with the diamond drill. And if one considers that the weight-registering means previously referred to permits the driller to obtain at all times the exact required weight on the drilling tools and avoid thus any unduly high rotating stress on the drilling pipe, one must come to the warranted conclusion that depths exceeding 8,500 feet will be reached by the diamond drilling equipment of superior construction and efficient operation.

Of course, the limitation in drilling depths is also a function of the nature of the formations. If these require to be cased off, the needed program of casing has to be projected carefully. When the measures stand up the drilling of open holes at great depths is easy. In the India case already mentioned, the well was drilled from 4,300 feet to 6,007 feet in a 4-inch open hole. As an indication of the great performance that can be accomplished with the diamond drill, it may be mentioned that in Mexico about 2,200 feet of 10-inch and about 3,800 feet of $8\frac{1}{4}$-inch casing have been set with the F. K. Sullivan machine and that the Stone machine powered with the $10 \times 10\frac{1}{2}$-inch engine designed for 15-inch holes has drilled 22-inch holes. The new Stone machine to be equipped with a 12×12-inch engine will drill 27-inch holes. An oil well should not be bottomed at a smaller diameter than 5 or 6 inches, and preferably 8 or 10 inches, in order to permit it to perform satisfactorily all drilling and subsequent operations such as bailing, fishing, shooting, and pump-

ing. But if it can be foreseen that no pumping will be needed, as is the case in oil fields where the rock pressure is such as to produce lasting gusher flows, diamond-drilled holes may be bottomed at a smaller size. In fact, the application of the diamond drill to drilling test wells probably originated through the necessity of finding a means of completing wells that had been drilled down to too small a size by cable or rotary tools, as happened in the well in India already cited.

In diamond drilling as well as any other drilling system, the program of casing has to be determined by giving due consideration to the necessity of putting in successive strings of casing to cut off water and other horizons and to protect deeper drilling against caving in of naked walls. In this last respect it is proper to point out that with diamond drilling the walls stand up better than with any other system, due to the fact that the strengthening of the walls by mudding is done more efficaciously (with greater speed and consequent centrifugal force), than under the standard rotary system, and that the walls are not subjected to the shaking effect produced by the pounding bit with the cable-tool system.

Soft measures being encountered in the Fernie shales and in the calcareous formations immediately overlying the reservoir limestone, the holes in Turner Valley must be cased off down to this limestone and it is likely that the holes could be commenced with fish-tail bits and protected by 10-inch casing.

It appears thus that diamond-drilling deep holes in Turner Valley down to the reservoir limestone will be safer and easier drilling than with either the cable tools or the standard rotary equipment. But where the diamond drill, intelligently operated, will prove its manifest superiority over any other drilling system, is in drilling against high gas pressure into the limestone capping the dolomitic reservoir and even into the reservoir itself. To give an indication of past performance of the diamond drill in this respect it may be mentioned that at Garber, Oklahoma, a well drilled and controlled by the diamond drill produced 35,000,000 cubic feet of gas under 1,700 pounds of pressure.

To handle the high gas pressures and prevent their accompanying freezing effect produced by the expansion of the gas, two means seem to be available. One would consist in preventing the gas from expanding at the bottom of the hole. The alternative would be to circulate, instead of water, another liquid having a lower freezing temperature.

To prevent the expansion and consequent freezing effect of the gas, the pressure can be controlled either by weighing down the circulating

water sufficiently with barium sulphate (baroid) or some other suitable substance, or adding the needed pump pressure to the hydrostatic pressure of the circulating fluid. This can be done easily, as the packed control head of the drill permits keeping a constant pressure on the circulating fluid while running in and pulling out of the hole.

The second method, that of letting the gas blow, and using a circulating fluid of low freezing point, would be appropriately accomplished by using oil, not only because of its very low freezing point (about 150° F. below zero), but also on account of its physical property of absorbing the naphtha contained in the wet gas, thus resulting in a diffused mixture of oil and naphtha with less tendency of becoming viscous under decreasing temperature. The oil and naphtha would be recovered before recirculation by having the flow of gas passed through a separator.

As a means of reducing the expansion of the gas at the bottom of the well, a counter pressure of about 1,000 pounds can be created at the surface, installing for that purpose a series of two or three valves, in order to guard against the freezing of the valve in use by having in readiness one or two spare valves. A general safety valve should be installed and manned permanently, to be opened instantly if the pressure were to rise too high at the counter pressure valve. It would also be desirable to use a diamond bit providing for a bigger space, say ⅛-inch, between the bit and walls, than the space of $^1/_{32}$-inch that is provided for by the regular diamond bit.

Of course, the two methods could be combined by weighing the oil down with one of the substances used in making paints, the most suitable of which would probably be white lead, or its substitute, asbestine, whose cost is only about one-third of that of white lead, at $2.00 a ton, and by adding a pump pressure to the hydrostatic pressure.

We believe that we are justified in concluding that the diamond drilling of very deep wells, even into the center of the true dolomitic petroleum reservoir of Turner Valley, is an engineering problem that can be solved successfully and must result in bringing in wells compared to which the Royalite No. 4 naphtha gusher, valuable as it is, will fade in importance. But such drilling of very deep wells on the flanks of the structure and in the extreme north and south parts of the field is bound to be expensive. This is particularly true for the extreme south end, where the old Record well, as indicated by its log, is bottomed at 4,327 feet in Benton formations, indicating the dolomitic reservoir at a very great drilling depth. This deduction is well confirmed by the

results obtained at the Home well and other wells situated nearly 3 miles north of the Record well and by the further fact that geological deductions point to the existence of a transverse normal fault with downthrow toward the south, situated about midway between the Home well and the Record well.

J. BILTERIJST[1]

621 LOUGHEED BUILDING
CALGARY, CANADA
June 20, 1927

MARBLE FALLS PRODUCTION IN SOUTH BEND, TEXAS

The following may be of interest to many geologists of north-central Texas, concerning the age of the deep producing horizon opened by the Panhandle Refining Company's E. N. McCluskey No. 7 in the South Bend field, Young County, Texas. This well was drilled from 4,199 feet to 4,219 feet on July 19, 1927, and up to date has produced approximately 600,000 barrels of oil, the gravity of which is 42 degrees.

Some discussion was excited among geologists and a report was current that the Ellenburger limestone, which is correlated with the Arbuckle limestone of Oklahoma, was the producing horizon in this well. To determine the age of this producing horizon, samples were sent to F. W. Rolshausen of the Humble Oil & Refining Company at Houston and his report came out as follows:

> *Sample No. 15,199.*—Dark brownish-gray non-dolomitic fossiliferous crystalline limestone. Numerous crystals of calcite noted.
>
> The absence of dolomite and the presence of echinoid spines, shell fragments and *Bryozoa*, are characteristic of the Marble Falls limestone.
>
> The samples of Ellenburger that we have examined in the laboratory are dolomitic and are non-fossiliferous.

The foregoing report confirms my opinion that this deep production is coming from the Marble Falls limestone.

J. P. BOWEN

WICHITA FALLS, TEXAS
December 1, 1927

[1]Introduced by T. G. Madgwick.

DISCUSSION

DISCOVERER OF McCAMEY FIELD, TEXAS

In his article on "Buried Ridges in West Texas," in the October, 1927, issue of this *Bulletin*, Sidney Powers mentions that the discovery well of the McCamey field was drilled by the Republic Production Company on the geological recommendation of the Marland Oil Company. Melvin J. Collins, who is now with Taylor and Link in San Angelo, discovered and mapped this structure (the Hurdle structure) in 1924 when he was working for The Texas Company. He recommended that they lease and drill the structure, but instead they took leases south of it. When Mr. Collins went with the Marland Oil Company in 1924, they leased the Hurdle structure on his recommendation. Therefore, the credit for the discovery of this field should go to Mr. Collins.

R. H. DURWARD

MIDLAND, TEXAS
November 2, 1927

CORRECTION

The titles printed under Plates 7 and 8 of the article by W. K. Cadman on "The Golden Lanes of Greenwood County, Kansas" in the November *Bulletin*, opposite pages 1170 and 1171, should be reversed. Plate 7 shows the subsurface on top of the Bartlesville sand and Plate 8 shows the Kansas City formation.

REVIEWS AND NEW PUBLICATIONS

On the Existence of a Salt Dome in the Oligocene Potassium Basin of the Upper Rhine. BY G. FRIEDEL. *Comptes Rendus de l'Academie des Sciences,* Paris, Tome 184, No. 18 (1927), pp. 1028-1031. (In French.)

Until recently the existence of salt domes in the Alsatian salt basin has not been known and the 2,000-foot thick salt deposits have been thought to be flat-lying or only gently dipping with some ordinary folding and faulting. In the area in which the potash is mined, which is the zone of the edge of the basin, the top of the salt lies at depths of 200 to 800 meters (650 to 2,700 feet) and no salt domes are known. In the zone of the center of the basin, the top of the salt normally lies at depths of 1,000 to 1,100 meters (3,300 to 3,650 feet) and as a rule the beds seem almost horizontal. In this latter zone, the correlation of well logs supplemented by exploration with the Schlumberger electric method of prospecting led to the location of the Meienheim salt dome, an elongated dome parallel to the edge of the Rhine graben. Depths to the top of the salt range from 150 to 180 meters (500 to 600 feet), although the top of the salt in the basin near by lies at a depth of nearly 1,100 meters (3,650 feet). A second dome is reported by C. Schlumberger to have been discovered by electrical exploration north, and on the prolongation, of the axis of the Meienheim dome.

Notes: Paul Weaver adds that in a letter to him, Mr. Leonardon of the Schlumberger Company states that the latter dome, the Hettenschlag dome, has been drilled and that gypsum was encountered at 65 meters (215 feet) and rock salt at 100 meters (330 feet).

The success of the Schlumberger method in working structures in sedimentary beds (in contrast to metalliferous deposits where the electric methods have greater applicability) is interesting. A report has come recently through several different sources from Roumania of a very pretty piece of successful work by the Schlumberger method in the Roumanian salt domes. The results of the testing out of the electrical methods, including the Schlumberger method, on oil structures in this country have seemed to indicate that the electric methods in their present state of development are impractical for the mapping of oil types of structures.

DONALD C. BARTON

HOUSTON, TEXAS
November 17, 1927

ABSTRACT

Radioactivity as an Aid to Petroleum Discovery. The Petroleum Times, London, October 22, 1927, p. 788.

Werner states that higher temperatures than normal exist over oil-bearing beds, and that this higher temperature was due to the oxidation temperature of the oil underground. He proposed to measure earth temperatures in drilling wells in an attempt to deduce from the results of such measurements, the probable presence of oil. This is a geothermal method. Gaedicke concurs in believing that higher temperatures exist, but believes that they are caused by radium rays which emanate from crude petroleums and that these rays always generate heat. Thus, he too favors the geothermal method of measuring earth temperatures. However, he also proposes another, that of measuring the radio-activity, believing that where the radio-activity is sufficiently strong and carbon is present, oil will be formed. He favors both the radio-activity and earth temperature measurements in drilling wells, saying that practice alone will show which method is the more certain and less expensive.

C. C. ZIMMERMAN[1]

PITTSBURGH, PENNSYLVANIA
November 28, 1927

RECENT PUBLICATIONS

GENERAL

The Earth and Its Rhythms, by Charles Schuchert and Clara M. LeVene. D. Appleton and Company, New York, 1927. xvi+410 pp., including index; illustrated. Price, $4.00.

"Comparison of Oils Derived from Coal and from Oil Shale," by Joseph W. Horne and Arthur D. Bauer. *Report of Investigations Serial No. 2832, U. S. Bureau of Mines*, Washington, D. C. Free.

GERMANY

"Die Faziesverhältnisse und ihre Beziehungen zur Erdölbildung an der Wende Jura-Kreide in Nordwestdeutschland," by W. Kauenhowen. *Petroleum Zeitschrift*, XXIII Band, Nr. 31 (Nov. 1, 1927), Berlin. Pp. 1324-46. Maps and bibliography. Original Publication in *N. Jahrbuch für Mineralogie*, etc., Beilageband LVIII, Abt. B (1927), pp. 215-72.

[1]Introduced by K. C. Heald.

"Ueber den Zusammenhang zwischen Erdöl- und Salztock-bildung in Nordwestdeutschland," by W. Kauenhowen. Report of the petroleum meeting at Hildesheim, June 12, 1927. Press of Wilh. Riemschneider, Hannover.

ILLINOIS

"The Story of the Geologic Making of Southern Illinois," by Stuart Weller. *State Geological Survey*, Urbana. Price, $0.10, postpaid.

TEXAS

"The Geology and Mineral Resources of the Fort Stockton Quadrangle," by W. S. Adkins. *University of Texas Bulletin 2738, Bureau of Economic Geology*, Austin, 1927. 164 pp., index, 8 text figures, 6 plates. Surface and subsurface, including fossils. Available data from well records of Pecos County as a whole. Economic geology includes oil and gas, salt, sulphur, limestone, and water.

"Exploratory Geology of a Part of Southwestern Trans-Pecos Texas," by C. L. Baker. *University of Texas Bulletin 2745, Bureau of Economic Geology*, Austin, 1927. 68 pp., index, 1 plate. Hudspeth, Culberson, Jeff Davis, and Presidio counties. Prospects for oil, gas, ores, and non-metallic minerals.

WYOMING

"Some Methods of Producing Flowing Wells in the Salt Creek Field and Their Effect on Gas-Oil Ratios," by K. B. Nowels. *Report of Investigations Serial No. 2833, U. S. Bureau of Mines*, Washington, D. C. Free.

THE ASSOCIATION LIBRARY

Headquarters acknowledges library accessions:

JAPAN

From National Research Council, Division of Engineering and Industrial Research:

The Industrial Transition in Japan, by Maurice Holland

From K. Uwatoko:

"Natural Gases of Igneous Origin in Japan"

MEXICO

From Departmento del Petroleo de la Secretaria de Industria Comercio y Trabajo de Mexico:

Bibliografia del Petroleo en Mexico

La Industria del Petroleo en Mexico

NORTH AND SOUTH CAROLINA

From Lloyd W. Stephenson:

"Additions to the Upper Cretaceous Invertebrate Faunas of the Carolinas"

VIRGINIA AND WEST VIRGINIA

From Albert W. Giles:

"The Origin and Occurrence in Rockbridge County, Virginia, of So-Called 'Bentonite'"

"The Geology of Little North Mountain in Northern Virginia and West Virginia"

THE ASSOCIATION ROUND TABLE

THIRTEENTH ANNUAL MEETING: CALIFORNIA

The thirteenth annual meeting of the Association will be held on the Pacific Coast in March, 1928. The first part of the convention, devoted to business and technical sessions, will be held in San Francisco on March 21, 22, and 23 with the Clift Hotel as headquarters and the Native Sons auditorium as meeting place. The entertainment and field trips will be provided at Los Angeles on March 24 and 25.

President Gester announces the personnel of the committee on arrangements as follows: chairman, E. G. Gaylord; vice-chairmen, C. R. McCollom and H. J. Hawley; program, W. S. W. Kew; publicity and exhibits, Joseph Jensen; hotel, J. T. Wood; registration, S. H. Gester; finance, J. E. Elliott; entertainment, Irving Augur; and transportation, H. J. Hawley.

Information concerning hotel accommodations and registrations will be outlined in a circular letter to be mailed by the local committee. Advance inquiries may be addressed to J. T. Wood, care of the Associated Oil Company, 79 New Montgomery Street, San Francisco.

The program of technical papers is now being arranged by W. S. W. Kew, and all matters regarding the presentation of papers should be submitted direct to Dr. Kew, whose address is Standard Oil Company, Box 1390, Station C, Los Angeles. Ample time will be provided for presentation and full discussion of papers. Projection machines and screens will be provided for the presentation of maps and illustrative material. Details can be arranged by correspondence with Dr. Kew.

Papers acceptable for presentation at the convention and publication in the *Bulletin* must be prefaced by a brief abstract, preferably less than 250 words, stating the principal points and conclusions. An original typewritten sheet of this abstract should be mailed before March to Dr. Kew. Papers presented before the Association are considered the Association's property, and they are not to be published elsewhere than in the Association *Bulletin*, except by arrangement with the business manager.

In the near future, transportation advices will be broadcast by special announcements by the arrangements committee.

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

E. G. WOODRUFF, consulting geologist of Tulsa, Oklahoma, has been busy in South America this winter.

MR. and MRS. ARIE VAN WEELDEN have been in Holland several months. Mr. van Weelden is geophysicist for the Roxana Petroleum Corporation at Dallas, Texas.

WILLIAM F. CHISHOLM, director of the minerals division of Louisiana Conservation Commission at Shreveport, Louisiana, addressed the Southwest division of the American Gas Association at Houston, Texas, last October on the subject, "Development of Conservation of Natural Gas."

LEON J. PEPPERBERG, consulting geologist and engineer of Dallas, Texas, is devoting considerable time to the interests of the Columbia Management and Engineering Corporation of New York City.

JOHN S. IVY, of the Palmer Corporation, Shreveport, Louisiana, presented a paper on "Fundamentals in Arriving at Gas Reserve in the Southwest Territory" before the American Gas Association, natural gas department, southwest division, at Houston in October.

DOUGLAS R. SEMMES joined the Alabama Geological Survey last fall to revise his earlier publications on petroleum possibilities in that state.

A. C. RUBEL, of the Union Oil Company of California at Los Angeles, R. VAN A. MILLS, of the U. S. Bureau of Mines at Bartlesville, Oklahoma, A. W. AMBROSE, of the Empire Companies at Bartlesville, and LESTER C. UREN, of the University of California, form a committee of the A. I. M. E. to provide a glossary of terms in oil production methods.

D. C. BARTON has written an article on "Applied Geophysical Methods in America." It appeared in *Economic Geology* for November, 1927.

WILLARD R. JILLSON is the author of "Geology of Oil Shales of Eastern United States" which appeared in *The Pan-American Geologist* for November, 1927.

KENT K. KIMBALL, consulting geologist, is associated with the J. Burr Gibbons Company of Tulsa, Oklahoma.

NELSON B. POTTER, formerly with the Tidal Oil Company at Tulsa, is now with the Indian Territory Illuminating Oil Company at Bartlesville.

EMIL BÖSE, formerly of the Bureau of Economic Geology of the University of Texas, died at Sabinal, Texas, on November 8, 1927. Death resulted from an automobile accident which occurred near Sabinal on September 9. At the time of his death Dr. Böse was in the employ of the Standard of California and was working chiefly in northern Mexico and adjacent regions in Texas.

J. H. PAGE, during the past five years with the J. B. Kirk Gas and Smelting Company, is now in charge of the geological and land departments of the Southern Kansas Gas Company, and HOMER H. CHARLES is geologist. The Southern Kansas has consolidated seventeen gas companies operating in eastern Kansas.

The Sullivan Machinery Company describes its new "Bravo-300" diamond core drill for hand, gasoline engine or motor drive, in Bulletin No. 80-E.

As most members of the Association from time to time need scientific reports and papers which are out of print, they may be interested in an arrangement whereby such reports can be purchased with a minimum of effort and expense. As part of the public service rendered by Princeton University, Laurence Heyl, chief of the acquisitions department of the University Library, maintains a list of volumes in the hands of collectors and second-hand book stores, both in America and abroad, and may thus locate articles not otherwise discoverable without prohibitive delay and expense. Mr. Heyl makes a small handling charge for arranging the purchase of such books. Anyone wishing to ask his assistance in such a connection should address him at 9 College Road, Princeton, New Jersey.

The Anglo-Persian Oil Company, Ltd., has undertaken to make an exhaustive examination of certain territories in Australia and New Guinea for the Australian Government. R. K. RICHARDSON, principal geologist of the Anglo-Persian, is leaving to take charge of the geological work.

The *Ecole Nationale du Petrole* of the University of Strasbourg, Alsace, is undertaking instruction in geophysics under the charge of P. GEOFFREY.

The Houston Geological Society has recently elected the following officers for the coming year: president, FRANK W. DEWOLF, of the Louisiana Land and Exploration Company; vice-president, MRS. JOHN F. (LAURA LEE LANE) WEINZIERL, consulting paleontologist; and secretary-treasurer, MARCUS A. HANNA, of the Gulf Production Company.

Geophysics, and in particular the seismic method now has another field to its credit in the East Hackberry, or Kelso Bayou, oil field on the east end of Hackberry Island in Cameron Parish, Louisiana. The Calcasieu Oil Company's Caldwell No. 2, located on the basis of seismograph work, came in recently for 1,000 barrels of 22° API oil from 3,996 feet.

SIDNEY PAIGE has moved to Caracas, Venezuela.

ROBERT D. GOODRICH has moved from San Antonio to 1421 West Harris Street, San Angelo, Texas.

FREDERICK B. PLUMMER, of Fort Worth, Texas, is consulting geologist for the Vacuum Oil Company.

BROKAW, DIXON, GARNER, and MCKEE are consulting geologists for Seagraves and Moody, of Houston, Texas.

CHARLES RENAUD, of the firm of Prettyman & Renaud, consulting geologists at Abilene, Texas, was injured in an automobile accident on November 4, 1927.

WOOD STANLEY, who spent the past year at El Paso, is living at Shawnee, Oklahoma.

JOHN F. HOSTERMAN, geologist for the Amerada Petroleum Corporation, has been transferred from Tulsa to San Angelo, Texas.

The committee on studies in petroleum geology, of the division of geology and geography of the National Research Council, is composed of K. C. HEALD, chairman, CARL H. BEAL, E. DEGOLYER, F. H. LAHEE, ALEXANDER W. MCCOY, SIDNEY POWERS, W. T. THOM, JR., CHESTER W. WASHBURNE, DAVID WHITE, and W. E. WRATHER.

D. DALE CONDIT, consulting geologist, 321 Dorset Avenue, Chevy Chase, D. C., sailed on November 29, 1927, for a trip of three months to Portugese East Africa.

JOHN N. STRIGEOFF, director of the petroleum industry of the Union of Socialistic Soviet Republics and professor in the Academy of Mines at Moscow, has been in the United States during the past several months, studying oil-field conditions and development.

A. R. DENISON is division geologist for the Amerada Petroleum Corporation at Fort Worth, Texas.

ROBERT WESLEY BROWN, of Houston, who recently completed a postgraduate course and received the degree of Ph. D. in geology at Chicago, has

returned from work in South America for the Standard Oil Company of Venezuela.

H. J. Tschopp, geologist, is again in Puerto Mexico, Ver., Mexico, with El Guila, after a stay in Switzerland.

W. E. Wrather, consulting geologist, announces the removal of his residence and office from 6044 Bryan Parkway to 4300 Overhill Drive, Dallas, Texas.

D. I. Mushketov, director of the Russian Geological Survey, sailed for Europe on November 16, 1927, after spending two months in the United States. He has a brief article on "Geological Exploration Work in Russia" in the *Engineering and Mining Journal* of November 26.

I. C. White, aged 79, state geologist of West Virginia since 1897, died at Johns Hopkins Hospital, Baltimore, Maryland, on November 24, 1927. Dr. White was probably best known in petroleum geology for his practical application of the anticlinal theory. He was president of this Association in 1919, and at the time of his death was an honorary member.

Frederick G. Tickell and Welton J. Crook, professors at Stanford University, have an article on "The Heat Treatment of Oil Well Casing" in *Oil Field Engineering*, for November, 1927.

Mr. and Mrs. Chase E. Sutton announce the arrival of a son on November 23, 1927, at Dallas, Texas. Mr. Sutton is with the U. S. Bureau of Mines.

W. Z. Miller, consulting geologist, has returned to Tulsa, Oklahoma, after spending the summer of 1927 in the Rocky Mountain region for the Gypsy Oil Company.

George R. Elliott has moved from Hollywood to 6311 West Eleventh Street, Long Beach, California.

The Geological Society of Northwestern Oklahoma, at Enid, has elected the following officers for 1928: president, B. B. Zavoico, geologist for Sinclair Oil & Gas Company; vice-president, Carl S. Ford, consulting geologist; secretary-treasurer, J. H. Van Zant, geologist for Healdton Oil & Gas Company. A committee has been appointed to issue for publication a monthly progress map of Lovell-Marshall field, showing all drilling wells with their depth and the producing wells with the names of pay sands, depths, records, and production.

D. M. Collingwood is in charge of magnetic work in the geophysical department of the Sun Oil Company.

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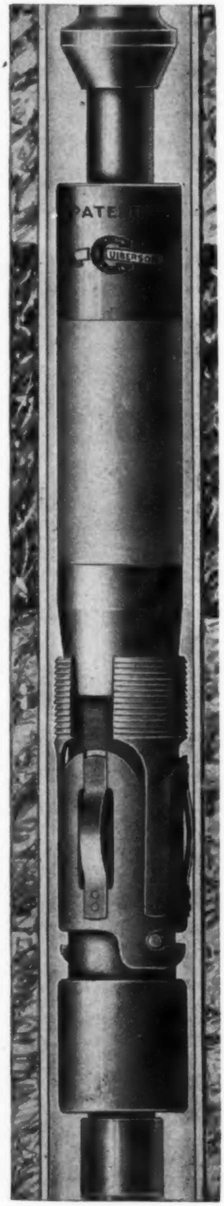

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